TM 1–232

WAR DEPARTMENT

TECHNICAL MANUAL

BASIC WEATHER FOR PILOT TRAINEES

April 22, 1942

Doc. coll
gift
mm inc.

HE'S NEVER BEEN RIGHT IN HIS LIFE! ★★

The epitome of stupidity, that's Aviation Cadet Knucklehead of the Army Air Forces. The little gent, noted for his deficiency in gray matter, will be the star of this manual. He'll commit more errors

FIGURE ZERO.

than a bush league third-baseman, and other aviation cadets are expected to profit by his mistakes. If Knucklehead weren't so dumb he couldn't hold his job. X marks the spot.

TECHNICAL MANUAL

BASIC WEATHER FOR PILOT TRAINEES

CHANGES No. 1 } WAR DEPARTMENT, WASHINGTON, May 26, 1942.

TM 1–232, April 22, 1942, is changed as follows:

41. Formation of a cloud.

* * * * * * *

c. Adiabatic.— * * *

(1) *Dry adiabatic lapse rate.*

* * * * * * *

(*b*) If the air parcel in figure 32② were at a surface temperature of 15° C. and were forced to the top of a 10,000-foot mountain, its temperature would be lowered 3°×10 or 30° C. and it would appear at the top with a temperature of −15° C. This, of course, is true if it remains dry; i. e., if there be no condensation or precipitation throughout this distance. When the air descends upon the leeward side of the mountain, the adiabatic compression would warm it up exactly the same number of degrees and it would arrive at the zero level at plus 15° C.

* * * * * * *

[A. G. 062.11 (5–11–42).] (C 1, May 26, 1942.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

J. A. ULIO,
Major General,
The Adjutant General.

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TECHNICAL MANUAL No. 1-232

WAR DEPARTMENT,
WASHINGTON, April 22, 1942.

BASIC WEATHER FOR PILOT TRAINEES

SECTION I

GENERAL

1. Weather service.—*a.* Normally, and whenever possible, weather service will be available to the pilot before flight. The service includes highly trained forecasters who are qualified to give to the pilot before flight a picture of the existing weather and a forecast of weather to expect during flight.

b. However, there are certain limitations to the service that can be rendered by the ground establishments. Even in peacetime, operating under most favorable conditions, forecasts are sometimes in

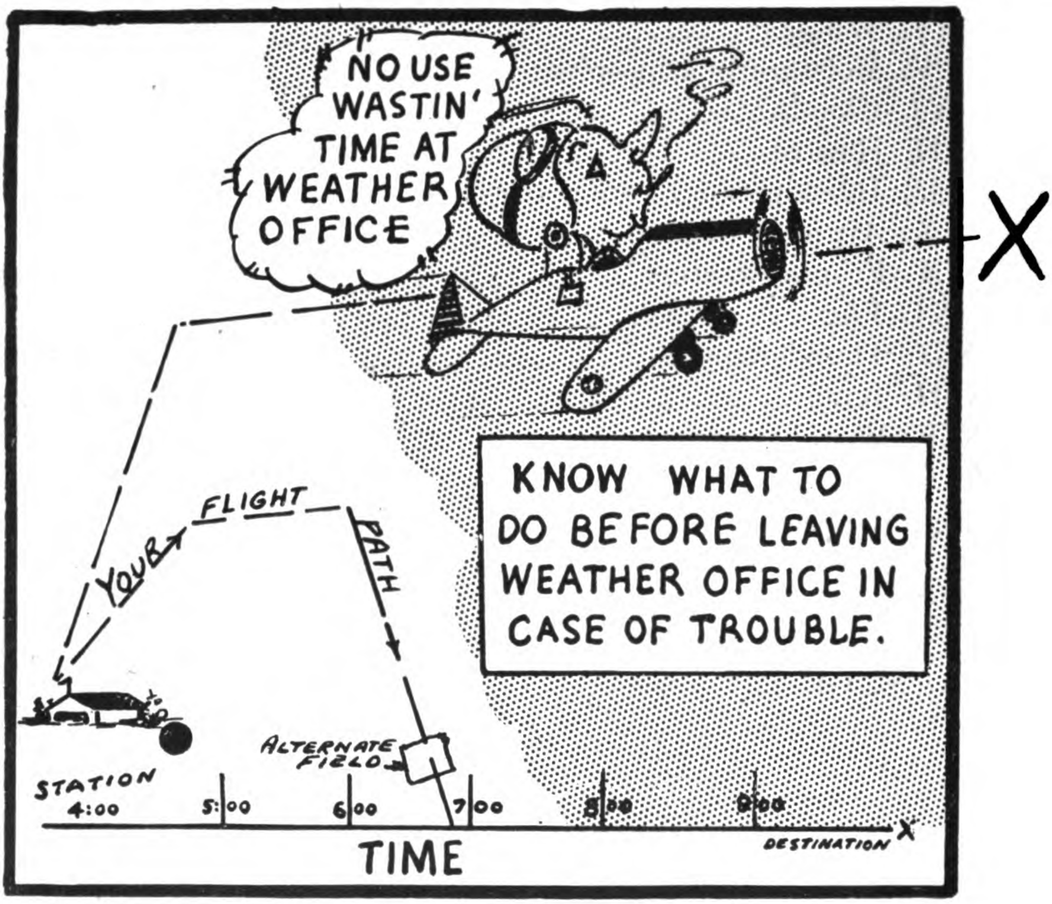


FIGURE 1.—To know or not to know!

error. The conditions imposed by war seriously handicap the weather service, especially in the more remote regions where adequate weather reports are not available. Under such conditions forecasts will be more frequently in error.

2. Weather troubles.—*a.* A large proportion of peacetime aircraft accidents may be attributed in whole or in part to weather. Usually, hindsight shows that the accidents could have been avoided. Realizing that the weather service cannot be perfect, a great deal of the fault must lie with the pilot. Usually, if the pilot had known

before he started what line of action he should take under unfavorable weather conditions, and then recognized those conditions in time, the accident would not have happened.

b. In wartime, flying operations must often be conducted in worse weather than in normal peacetime operations, and with a less adequate weather service. Therefore, in time of war it is much more important that the pilot know weather than it is in time of peace.

3. **Accidents.**—In time of peace, any accident that results in injury to personnel or damage to equipment is regrettable. In war, loss of trained personnel and irreplaceable equipment may represent a tragedy not only to the individuals concerned but to the operation in which they are engaged.

4. **Functions of weather service.**—*a.* Briefly, the weather service has two functions. One is to forecast the weather that is expected a day or more later, so that plans can be made to take advantage of weather conditions. The other is to give the pilot information that will increase the probability for successful outcome of his flight. Only the latter is of direct concern to the pilot. The pilot needs to know the information normally available to him, and how to use that information to his advantage during flight.

b. In addition to a great deal of weather information normally given to the pilot before his flight, he is constantly in a position to gain more information during his flight. For instance, he can see clouds, feel bumps, and read the temperature at his flying level. It is equally important that he know how to use such information.

5. **Pilot weather functions.**—*a.* The weather service tells the pilot what weather to expect. However, most weather trouble is caused by encountering unexpected weather, that is, when the weather service or the weather forecaster is wrong.

b. It is highly important that the pilot place the weather service rendered him in the correct perspective. He should have faith in the weather service knowing that the forecaster knows better than he does what to expect. However, he should not have blind confidence. The forecast is almost always correct generally but cannot always be perfect in all respects that concern the man in the airplane. A forecast that icing conditions will not be encountered at a certain level does not help the pilot when he encounters ice at that level. It is then up to the pilot to decide what to do—the forecaster cannot help him.

c. The proper pilot functions can be stated as follows:

(1) Before flight, get a picture of the weather that is expected over the whole area that may be covered during the proposed flight. This does not mean just the weather along one line at a certain altitude,

but the weather over the whole area at all operating altitudes. Even though no trouble is expected, attempt to decide before flight what to do in case unexpected trouble is encountered.

(2) During flight, first and constantly, check the forecast of flight weather against his own observations. Such a check will usually verify the correctness of the forecast, in which case the pilot is benefited by peace of mind. Occasionally, the check will show that the forecast was not correct. Then the pilot must make certain decisions.

(3) If the forecast is not correct, wherein is it wrong? Is a change in flight plan desirable?

(4) If a change in flight plan is indicated, how should it be changed?

d. No general rules can be given to solve these problems. We cannot say always turn around, or always go up, or down, or to the right. The pilot must make his own decision, and it must be based on his understanding of the situation gained before take-off and his own interpretation of the weather phenomena he observes during his flight.

6. Relation between pilot and weather service.—*a.* We are used to ground services that are directly concerned with our airplane and other operating equipment. We recognize the fact that a pilot does not have to know everything that the engine mechanic, instrument man, radio man, etc., knows. We need to know how they function, and what we can reasonably expect of them. It is their business to put the equipment in the best possible condition for flight. When the airplane is released to the pilot, it means that each man responsible for the ground work has done the best he can do and that each man thinks his equipment will give satisfactory performance during that flight.

b. However, we still need instruments. Why? In case something is not going as the ground man thought it would, these instruments would indicate it in time for you to do something. You do not want to wait until you run out of gas to decide what to do. You want to know ahead of time when you are going to run out of gas, and know it far enough ahead to permit successful completion of the flight.

c. The release of the airplane constitutes the ground man's forecast. A note in form 1 is his way of telling us "Watch for possible trouble." The rest is up to the pilot. It is his business to operate the equipment; once he is in the air, the men on the ground cannot help him.

d. The weather service should be considered in the same light. The forecaster tells us what weather to expect, and points out the possibilities of certain hazardous conditions that might be encountered during

flight. Once the pilot is in the air, he is on his own. The ground service cannot help him any more.

e. A pilot who did not know how to use his instruments would be worthless. In fact, he would not become a pilot.

f. Weather cannot be read on a dial. Cloud form, temperature, bumps, etc., are to weather what the instruments are to the equipment in the airplane. A pilot who does not know how to use the information gained from these "weather instruments" is in about the same predicament he would be in if he did not have any instruments in his airplane.

7. Learning weather.—*a.* Learning weather is much the same as learning anything else about flying. It is not simple. It cannot be made simple. It takes time and application on the part of the student, and continued application on the part of the pilot during his whole flying career. Nothing about flying is simple; all attempts to simplify it have shown that a difficult matter cannot be made simple. However, all matters concerned with flying are within the capabilities of a normal individual.

b. A student beginning his study of weather may well wonder, "How in the world am I going to learn whether a bump means that I should go up, down, front, back, right, or left?" A bump may mean any one of these, and also indicate how far up, down, etc.

c. Remember your first airplane ride. Suppose you had stepped into a modern bomber for your first ride? You would have encountered some hundreds of instruments, and you would have wondered, "How in the world am I ever going to learn which is which, much less what each means?" Even a basic trainer would have appeared to require a superman.

d. Learning weather is certainly less difficult than learning the proper use of all the instruments, controls, gadgets, etc., in a modern airplane. However, the importance of learning weather is comparable to learning the proper use of the airplane equipment.

8. Limitations of weather text.—*a.* None of us would maintain that flying could be taught out of a book or in a classroom. Some parts of flying can be so taught; other parts require practice. A great deal about weather can be learned from books, and in classrooms, but not all. Practice is still necessary, and flying in weather cannot be practiced in a classroom.

b. A pilot, upon receipt of his wings, would be very foolish to think he knew everything needed to know about flying. He does not know everything. However, he does know enough so that he

can improve his own abilities. He has the foundation so that experience combined with study will keep him up to the best of them.

c. Similarly, weather training gives the pilot a foundation. Completion of this training will give the pilot an idea of how to go about using the weather service, and how to go about deciding the meaning of the things he can observe for himself. In short, he will know what to look for when he is flying.

FIGURE 2.—Everything in manual is important to pilots.

9. Use of this manual.—*a.* This manual is especially designed for use in the weather courses given in Army Air Force flying schools. The text itself does not constitute a complete weather course. It is designed for use in conjunction with lectures, quizzes, and map and teletype work.

b. The text has been prepared especially for the pilot. A great deal of information that is important to the ground weather man but not to the pilot has been omitted. On the other hand, some matters are included that are not so much concerned with weather, but are important to the pilot. Where practical, application of principles to

flying are pointed out to show how the pilot should attack weather problems. It is obviously impractical to point out all applications of all principles.

c. In his study, the student should realize it is highly important that he thoroughly understand the first few sections. It is necessary to acquaint the student with certain fundamental material which sometimes does not seem to have a direct bearing on flying an airplane. An understanding of temperature, pressure, winds, and moisture in the atmosphere, however, is essential to understanding weather. No material is included that is not important for the pilot to know.

10. Weather practice.—*a.* Wartime flying frequently means weather flying and instrument flying. Both should be practiced as much as possible. It is not necessary to fly in dangerous weather to practice weather flying. In fact, when dangerous conditions are encountered, it is too late to practice. Practice should be aimed at avoiding dangerous conditions, which really means recognizing dangerous conditions in time to avoid them. It is equally important that the pilot recognize conditions which are not dangerous, so that he will know when he should continue his mission as planned.

b. Each pilot should make it a habit to do certain things on each flight. First, before any flight, he should, when possible, get a picture of weather to be expected over the area of operation at different altitudes. Second, he should check constantly to see if conditions are as expected, and, if not, wherein they are different. Also, he should ask himself, "What should I do in case of . . . ?"

11. Tactical use of weather.—*a.* The student, and the pilot, should always bear in mind that wartime flying frequently makes concealment highly important. Under such conditions, weather that is normally considered a nuisance may be used to great advantage. Improper use of weather may result in an unsuccessful mission.

b. The scope of the present war is such that no one knows where he may be flying in the future. In some areas in which our Air Forces are, or will be operating, the weather service cannot be very good, simply for lack of weather data. Thus, this manual is designed to point out principles that may be applied in any theater of operations. Examples given deal largely with North American weather because we are familiar with North America. However, it is not intended that special emphasis should be placed on the particular condition, but on the principle demonstrated by that condition. Knowing what the weather would be in San Antonio does not benefit the pilot in Africa. However, knowing what makes the weather the way it is in San Antonio will help the pilot anywhere in the world.

12. Weather factors.—*a.* Certain factors generally control weather. Primary factors are temperature and moisture content of the air at different levels. Moisture content usually does not change rapidly. Temperature may change rapidly, particularly near the surface of the earth. Such changes account for a great deal of the weather that is of interest to pilots. Temperature is probably the most important consideration of the pilot.

b. Moisture and temperature practically tell the pilot the kind of air with which he has to contend. However, winds bring the air from which it acquires its temperature and moisture characteristics. Winds are controlled by pressure. Pressure, in turn, is largely controlled by temperature.

c. Terrain has certain effects on the air, depending on temperature, moisture, and winds. The effect of water areas is different from land areas. Upslope is far different from downslope.

d. Fronts have an effect similar to terrain except that we can fly under the front while we canont fly under the surface of the earth.

e. The major hazards (fog, thunderstorms, and icing) depend primarily on temperature and moisture content, and are influenced by winds, terrain, fronts, etc.

f. Thus, the importance of temperature and moisture is clear. However, another factor is of vital importance; i. e., the degree of stability of the air—whether or not there is a tendency for overturning of the air. The importance of understanding this factor can be understood from two simple statements. Fog generally cannot exist in unstable air. Thunderstorms cannot develop in stable air.

g. Understanding of the interrelation of these various factors is understanding weather.

Section II

TEMPERATURE

13. Reports.—Temperature data are included for each station on the weather map and teletype reports. These are surface temperatures. All surface temperatures are reported in degrees Fahrenheit.

14. Temperature scales.—Surface temperatures are reported in degrees Fahrenheit, probably because the public is only familiar with the Fahrenheit thermometer. However, the centigrade thermometer

FIGURE 3.

is used in most scientific and technical work. Thermometers in airplanes are graduated in degrees centigrade. Therefore, the pilot should be familiar with both scales and be able to convert temperatures from one scale to the other. Figure 4 shows a thermometer graduated

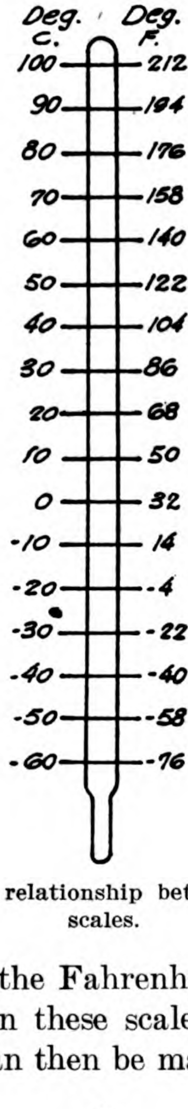


FIGURE 4.—Thermometers showing relationship between the centigrade and Fahrenheit scales.

in both the centigrade and the Fahrenheit scales. Note the freezing and boiling temperatures on these scales, and remember that 5° C. equal 9° F. Conversions can then be made when necessary.

15. What is temperature?—Temperature indicates the amount of heat or the degree of heat energy present. Adding heat or heating a substance raises its temperature. At absolute zero (−273° C.) a substance has no heat. The molecules will be at rest; they have no energy. Thus absolute zero is the lowest possible temperature. Addition of heat would cause movement of the molecules, with a consequent rise in temperature. The more heat added, the faster the molecules would move and the higher the temperature would be. Addition of heat causes an increase in energy content. Since heat plays an important part in all weather phenomena, the measurement of heat, heating of the earth's surface by the sun, the transfer of heat from one part of the atmosphere to another, and the temperature variation with altitude should be studied.

16. Measurement of heat.—*a.* Heat is usually measured in calories. A calorie is the amount of heat necessary to raise the temperature of 1 gram (1 cubic centimeter of water) 1° C. Thus, in the case of water, consider 10 grams of water at 0° C. Addition of 10 calories of heat will raise the temperature 1° C. If enough heat is added to raise the temperature to 100° C., there will have been added 1000 calories of heat. Thus, temperature measures the degree of heat.

b. The specific heat of a substance is the number of calories necessary to raise the temperature of 1 gram of that substance 1° C. Since just 1 calorie is necessary in the case of water, the specific heat of water is 1. The specific heat of ice is 0.5 which means that it takes ½ calorie of heat to raise the temperature of 1 gram of ice 1° C. Thus, 5 calories of heat would be required to raise the temperature of 1 gram of ice at −10° C. to 0° C.

17. Insolation.—*a.* The sun may be regarded as the sole source of heat energy that is supplied to the earth's surface and the atmosphere. The amount of heat energy received by the atmosphere from other stars and directly from the earth itself is negligible.

b. The earth receives heat from the sun by radiation (the transfer of heat by wave motion). This radiation from the sun is called *insolation*, "sol" being Latin for sun.

c. All bodies radiate. The hotter the body, the more intense is the radiation, and the character of the radiation varies with the temperature of the body. Thus, if a cold piece of metal is heated, it first throws off radiation which is invisible to the human eye, but which may be felt as heat. This invisible radiation at relatively low temperatures is characterized by long wave length, and is often referred to as low-temperature radiation. As the temperature in-

creases, the metal begins to glow with a dull red color (visible radiation), and with further heating, the color brightens until finally the metal becomes white. These changes in color are due to the wave length of the radiation becoming gradually shorter. Radiation in the short wave length is therefore often referred to as high-temperature radiation.

d. The temperature of the sun's surface is about 6,000° C., whereas the average temperature of the earth's surface is about 10° C. The earth's radiation is therefore invisible (low-temperature or long wave radiation), whereas the sun radiates mainly in the visible range (high-temperature or short wave radiation).

e. Insolation (sun's radiation) is absorbed by the surface of the earth and increases the temperature of the earth's surface. This direct radiation of the sun is absorbed only to a slight extent by the atmosphere because the air is almost transparent to high-temperature radiation. This heat is re-radiated back into space by the earth as low-temperature radiation. Part of this radiation is absorbed by the clouds, and a considerable portion of it by the water vapor in the air. Thus the water vapor in the air is analogous to the glass of a greenhouse. Like the glass of a greenhouse it lets through practically all incoming short wave radiation from the sun, and it tends to prevent the long wave re-radiation of the earth from getting back into space.

f. Although insolation increases the temperature of the earth's surface, it is common knowledge that the same amounts of heat will cause different temperature changes, depending on the surface. The sand on a beach becomes hot while the sun is shining on it. The temperature of the water hardly rises. The temperature in a forest will rise, but not as much as the temperature of the sand. It should be kept in mind that this variation in temperature is not due to a variation in the amount of heat received from the sun (insolation), but due to a difference of absorption and reflective power of the surface receiving the insolation.

g. The amount of insolation reaching the surface of the earth from the sun depends on the angle at which the sun's rays hit the earth. The more directly overhead the sun is, the more rays strike the earth's surface per unit area. This is illustrated by the fact that ordinarily the earth is warmer at noontime than at sunset and, too, that higher temperatures are recorded in summer, when the sun's path is more directly over the northern hemisphere, than are recorded in winter.

h. The amount of insolation reaching the earth's surface is also limited by clouds; a solid cloud deck can cut off by reflection as much

as 75 percent of the incoming solar radiation, but these same clouds also hold in the terrestrial radiation that would otherwise be radiated back into space. In fact, clouds are very helpful at night in retaining the heat (almost 100 percent) that has come to the earth from the sun during the daytime (greenhouse effect).

i. There will also be very little increase in temperature of a snow-covered surface since snow reflects most of the insolation.

j. Late in the day, when the sun begins to approach the horizon, the amount of outgoing radiation from the earth exceeds the incoming radiation from the sun. That is, more heat is being emitted from the earth per unit surface than is being received by the same surface. After the sun disappears, the earth is not receiving any heat, but it continues to radiate heat outward. The earth's surface cools. Radiation from a body results in lowering the temperature of the body.

k. As with insolation, the amount of change of temperature depends on the kind of surface. Considering again the beach, the sand becomes quite cold at night. The temperature of the water remains practically the same. In the woods, the temperature goes down but not so much as the temperature of the sand. Why is there such a difference in the diurnal (daily) variation of temperature over different surfaces such as land and water? Why does the surface of a large body of water vary so little in temperature between day and night (maximum 1° C.), whereas the temperature of a land surface may be as much as 20° C. colder at night than in the daytime?

l. The earth is a very poor conductor. Thus, the heat absorbed is accumulated in the upper few inches of the earth and as a result the temperature of the earth's surface increases appreciably during the day. On the other hand, when water absorbs heat, heating of a deep layer takes place due to the mixing caused by winds and waves which helps to distribute the heat. A good deal of the heat absorbed is expended in evaporating water. Then, too, water has a higher specific heat than land; i. e., it takes more calories of heat to raise the temperature of a unit volume of water 1° C. than it does to raise the temperature of an equivalent amount of land 1° C. As a result of these three factors, there is no appreciable increase in the temperature of the sea surface during the day. Likewise, when radiational cooling is taking place at night, heat is lost from the entire water body instead of just the surface as in the case of land. Thus, there is appreciable diurnal variation in temperature over land and very little over water.

18. Temperature variation with height.—*a.* When a pilot takes off in an airplane and gains altitude, he notices a decrease in temperature. While the temperature at the surface may be quite comfort-

able for "shirt sleeve" attire, a pilot will be thankful for heavy clothing if he goes aloft to 15,000 feet and finds the temperature several degrees below zero centigrade.

b. The temperature variation with height is important to the weather man. When the data are available, they furnish a definite aid in the forecasting of flying weather. Temperature variation data may be obtained by a pilot flying a plane. He records the temperature of the air at various flying levels, together with altitude at which he read the temperature.

c. The change of temperature, with respect to altitude, may be shown by means of a table. This table shows that, for each 1,000 feet rise above the surface, the temperature decreases 2° C. or, we may say, the temperature varies directly with altitude.

TABLE I

Altitude	Temperature (°C.)	Altitude	Temperature (°C.)
Surface	20	3,000 feet	14
1,000 feet	18	4,000 feet	12
2,000 feet	16		

d. The variation of two quantities with respect to one another can be shown by graphic representation; that is, these values can be plotted on a graph precisely the same thing as shown in table I. To represent this we draw a vertical line to show height, and a horizontal line to show temperature, as indicated in figure 5.

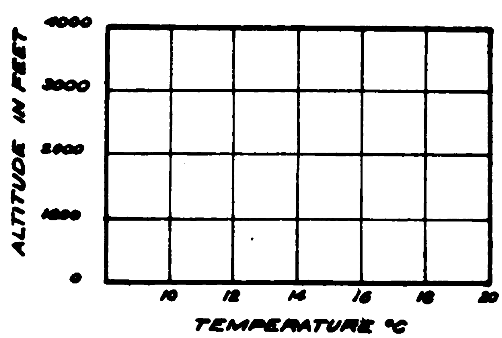


FIGURE 5.—Temperature-altitude graph.

By inspection of our graph, we see that the horizontal lines represent heights, increasing as we go up. The vertical lines represent temperature, increasing as we pass from left to right.

e. To represent the data shown in the table we plot them upon the graph. By comparing the table with the graph we see that at 4,000 feet the graph shows a temperature of 12° C., and 14° C. at 3,000 feet. Thus, the line drawn connecting these points shows the temperature at any elevation. If we wish to know the temperature at 3,500 feet, we look on the graph and find it to be 13° C.

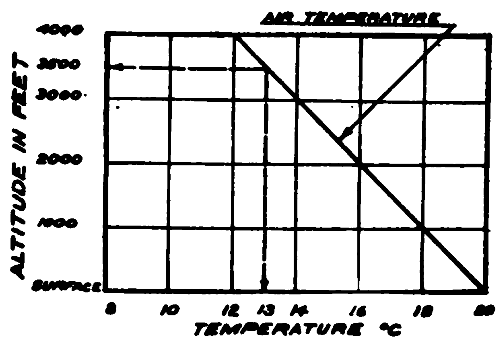


FIGURE 6.—Plotted air temperature.

f. The line we have represented on the graph is one which has been found to be the average temperature variation with height. Due to different amounts of heating and cooling we seldom will experience a uniform decrease in temperature of 2° C. per 1,000 feet. The weather phenomena we experience result, in part, from this temperature variation with height. For forecasting purposes and analysis, it is highly important that this variation with height is known each day. The average of 2° C. per 1,000 feet results from

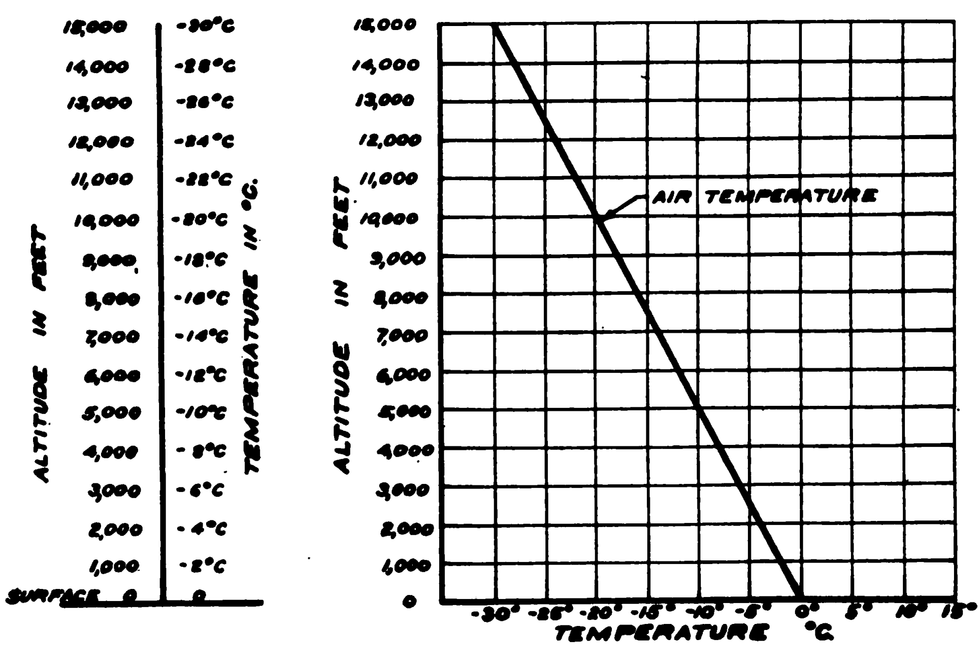


FIGURE 7.—Air temperature over North Pacific in winter.

averaging thousands of observations over the surface of the earth for a period of time.

19. Transport of heat.—*a.* Different temperatures occur over large areas of the earth's surface. For instance, winter temperature over the North Pacific is about 0° C. Going aloft, we would observe that the air temperature decreases about 2° C. per 1,000 feet as shown in figure 7.

b. Now suppose that this same air moves over Canada where the surface temperature is about −30° C. Since the air is warmer than the surface, heat tends to flow from the air to the surface. The air near the surface will be affected very rapidly; the air farther from the surface more slowly. This will result in a rapid decrease of the temperature of the air near the surface. The following diagrams show air temperatures at different time intervals:

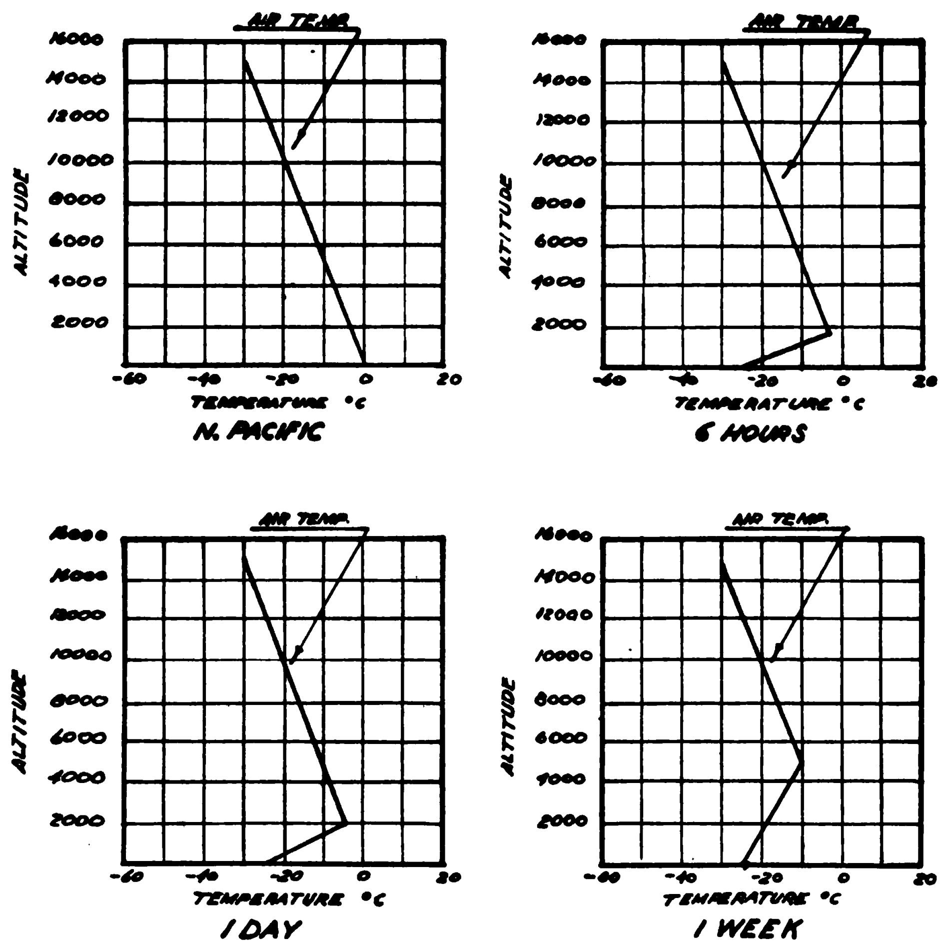


FIGURE 8.—Change in air temperature as air passes over cold land in winter.

The preceding is a representation of actual conditions observed over cold areas in winter. It will be noted that the temperature of the air aloft is changed very slowly. It would require about a month for

the surface (cold) temperature to affect the air as high as 10,000 feet.

c. Now suppose that the same kind of air moves south and eventually over the Gulf of Mexico. Assume that by the time it reaches the

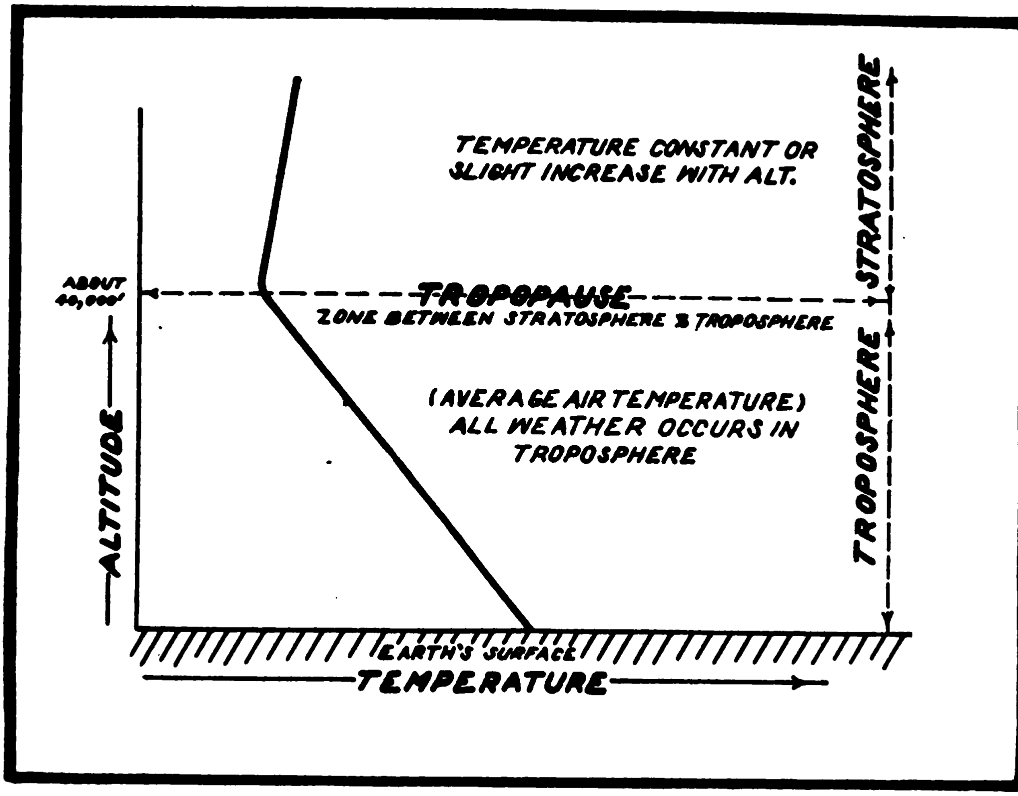


FIGURE 9.—Air temperature aloft.

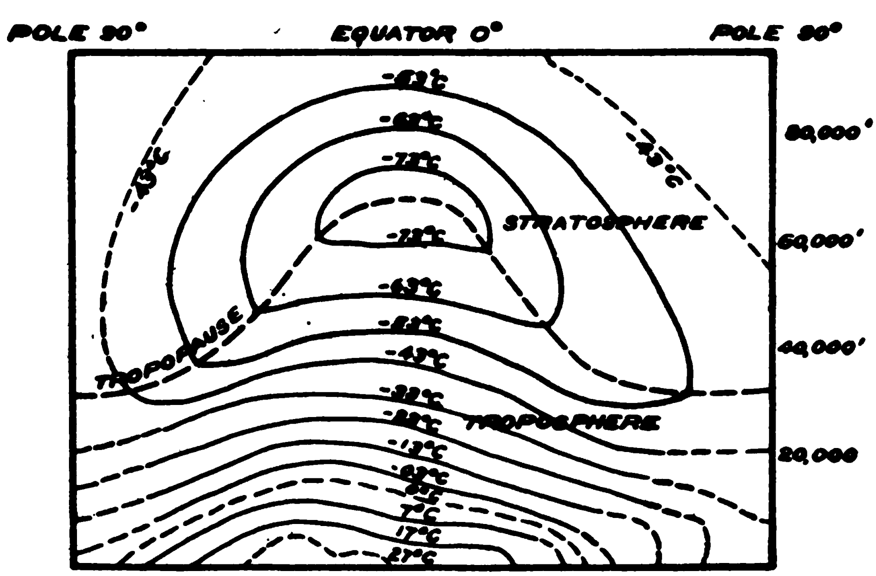


FIGURE 10.—Temperature distribution.

Gulf, the air temperature distribution with height will again be similar to that over the North Pacific, with surface temperature about 0° C.

d. The temperature of the Gulf is about 20° C. Again, the air near the surface will rapidly assume the surface temperature; i. e., 20° C. This heating causes expansion of the air, which renders it lighter than the air above. Thus, the heavier air above will displace the lighter air, forcing the latter aloft. The heat absorbed by the air near the surface will thus be rapidly transported to higher levels. Such transport of heat is termed convective transport. The heating of the surface air with no corresponding heating of air at higher levels produces an unstable or top-heavy condition. This in turn results in vertical air flow, the colder air coming down, displacing the warm air and forcing it aloft.

e. It will be noted that surface heat is transported to high levels in a short time due to the convective currents set up. On the other hand, heat from the air is transported down to the surface slowly, since surface cooling of the air produces a stable condition which precludes convective currents.

f. The average or normal temperature variation with height is 2° C. per 1,000 feet in the troposphere. The meaning of the terms troposphere, tropopause, and stratosphere will be understood from the diagrams shown in figures 9 and 10.

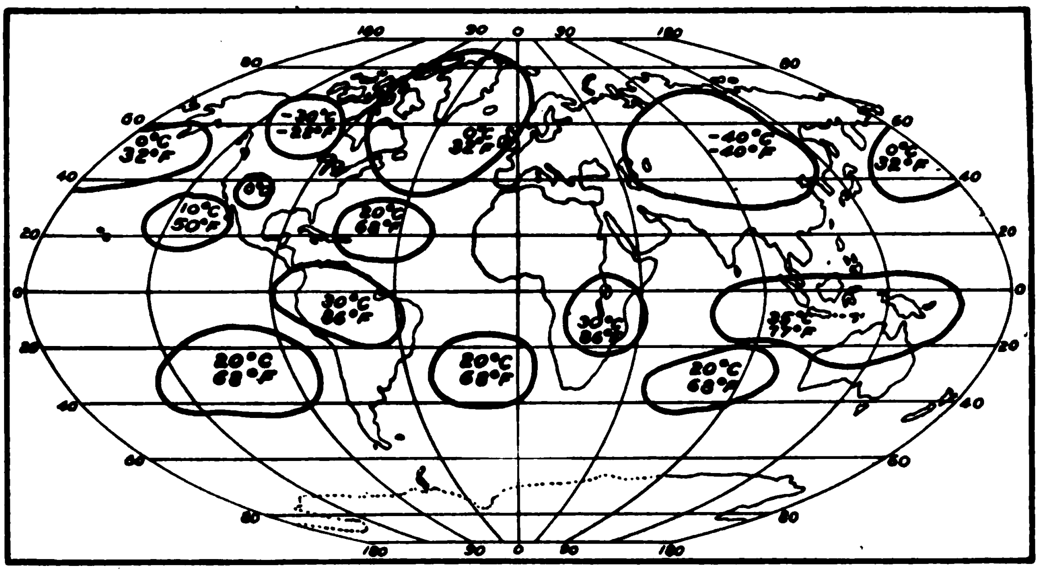
20. World temperatures.—Figure 11 shows the distribution of temperature over the surface of the earth in January and July.

QUESTIONS

1. Of what value is it to the pilot to be acquainted with both the centigrade and Fahrenheit temperature scales?
2. Give a simple relationship between °F. °C.
3. Define specific heat. What are the specific heat values for ice and water?
4. How many calories of heat would be required to raise the temperature of 2 grams of water 10° C? 2 grams of ice 10° C?
5. Define insolation.
6. Distinguish between solar radiation and terrestrial (earth) radiation.
7. What is the chief heat absorbing agent in the atmosphere?
8. The heating of the atmosphere is effected from below. Explain how this happens.
9. Would you expect more or less radiational cooling on a clear or on a cloudy night? Explain your answer.
10. If the temperature at sea level is 9° C., what would be the approximate temperature at an elevation of 4,500 feet above the station (assuming the average decrease of temperature with height)?

11. Plot and draw the air temperature curve from the following data obtained from an upper air sounding:

Altitude (feet):	*Temperature (°C.)*
Surface	20
1,000	18
3,000	13
6,000	8
10,000	—1



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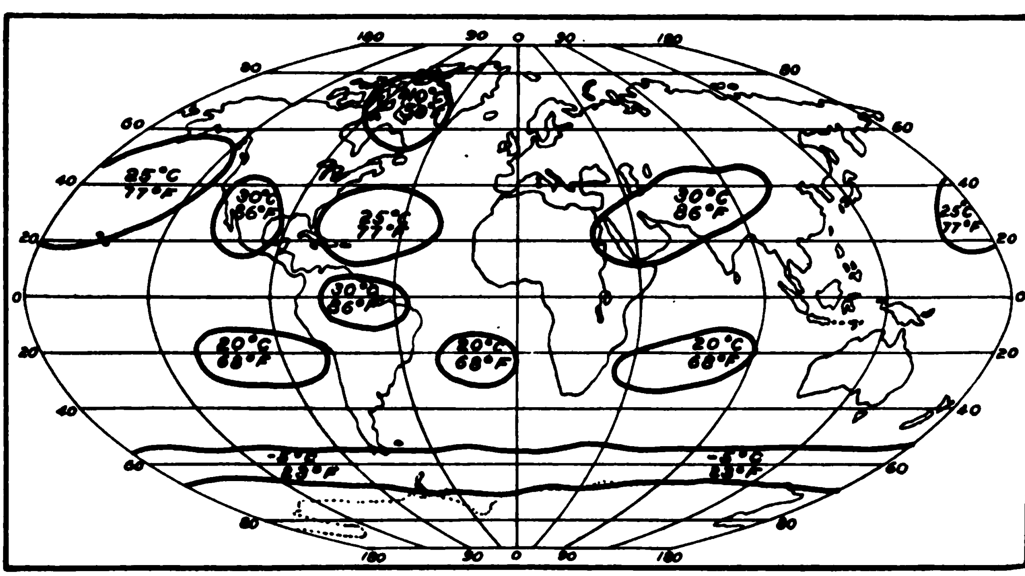


JULY

FIGURE 11.—World temperatures.

12. If the air in question 10 represented air over the Gulf of Mexico in winter, how would you expect the air temperature to change if the air moved northward over the United States? Illustrate by means of simple graphs.

13. Discuss briefly, with the aid of simple graphs, the changes that take place in the air temperature when cold air moves over warm ground.

14. Define troposphere, tropopause, and stratosphere.

15. Why and where may an updraft be experienced when flying from water to land on a hot summer day?

SECTION III

PRESSURE

21. Reports.—Pressure reports are made to the nearest tenth of a millibar. In order to save space and time just the last 3 figures are used both on teletype and the weather map. Thus a pressure of 1,013.2 millibars would be reported over teletype as 132 and would be shown on the weather map as 132. Since pressures at the earth's surface seldom exceed 1,050.0 millibars nor seldom fall below 960.0 millibars, no confusion need arise as to whether a pressure is greater or less than 1,000.0 millibars. Thus, a report such as 357 would be 1,035.7 millibars and a report such as 896 would be 989.6 millibars.

22. Pressure standards and scales.—*a.* Pressure is defined as force per unit area. Pressure is measured by some form of barometer. The first barometer consisted of a tube of water with a vacuum at the top. It was found that the water rose in the tube about 34 feet. This means that the pressure of the air was sufficient to support a column of water 34 feet high. Due to practical difficulties of using water, mercury was substituted in a similar type of tube. Various refinements have produced the modern mercury barometer. It is found that mercury will rise in such a tube about 30 inches if the pressure is measured at sea level. The mercury barometer can be read with extreme accuracy, but is delicate and awkward to handle. For practical use, when extreme accuracy is not required, a mechanical pressure instrument, the aneroid barometer, is used.

b. Figure 12 shows the principle of the mercury barometer. The glass tube is filled with mercury and inverted into a cup of mercury.

The height H depends upon the barometric pressure; so pressure may be measured by height alone. The height H, if measured in inches, will give the barometric pressure in inches of mercury.

c. If a mercury barometer were constructed with a cross section of 1 inch, it would be found that the column of mercury supported by the air at sea level would weigh about 15 pounds. Sea level pressure equals 15 pounds per square inch.

d. For scientific work, pressure is converted into millibars, which is equally convenient for practical purposes and is now replacing other pressure units. However, it will require many years before the other units are entirely replaced. It is important then, for the pilot to know the relationship between the various pressure units commonly used.

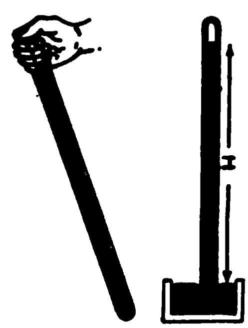


FIGURE 12.—Mercury barometer.

e. In order to construct useful weather maps, it is necessary to reduce all observed pressure to a common level, which is normally sea level. Standard sea level pressure assumes a so-called standard atmosphere, such an atmosphere having a surface (sea level) temperature of about 15° C. and a normal temperature variation with height.

f. Standard sea level pressures are here given in various units:

(1) 29.92 inches of mercury equals 760 mm of mercury equals

(2) 1,013.2 millibars equals 14.7 pounds per square inch.

g. For practical purposes, the pilot should remember that approximately 30.00 inches equals 1,000 millibars equals 15 pounds per square inch. These relationships are accurate enough.

23. Isobars.—*a.* Isobars are lines drawn through points of equal pressure on weather maps. Army Air Force practice is to draw isobars for all pressure expressed in whole millibars divisible by three as 999, 1,002, 1,005, 1,008, etc.

b. Since pressures are constantly changing, isobars are drawn to obtain an easily grasped picture of pressure systems.

24. Pressure systems.—Isobars on a weather map show various areas of relatively high pressure, and other areas of relatively low

pressure. Weather is caused primarily by variation in pressure thus shown on the weather map. However, it is the relative pressure of various pressure systems that primarily concerns us. For example, a pressure of 1,010 millibars would be low for Chicago in the winter, whereas this same pressure would be high for San Antonio in the summer.

25. Pressure gradient.—*a.* Pressure has been defined as force per unit area. If the force is exerted equally in all directions, it will have no apparent effect. However, the existence of a high pressure area next to a low pressure area means that a certain net force is acting toward the low pressure.

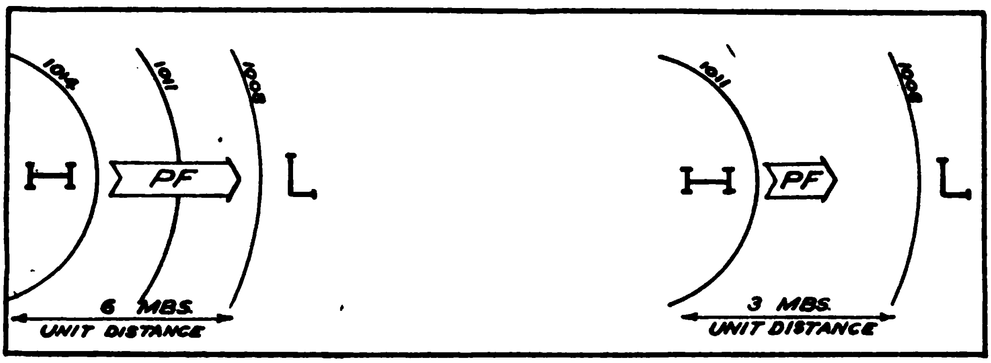


FIGURE 13.—Principle of pressure gradient.

b. The intensity of this force (see sec. IV) determines wind velocity and is indicated by the spacing between isobars, or the pressure gradient. The closer the isobars the steeper is the pressure gradient and the greater the pressure force, and the greater the pressure force the stronger is the wind.

26. Importance of pressure.—Knowledge of pressure is important in determining altitude, understanding the functioning of altimeters, and forecasting weather.

27. Effect of altitude.—*a.* Air is a compressible fluid composed of about 1/5 oxygen and 4/5 nitrogen. What this means can best be shown by comparing pressure lapse in air with pressure lapse in water, which is considered not compressible.

(1) Going down in the ocean we would find that the pressure increases in direct proportion to depth. The pressure will increase approximately 15 pounds per square inch for each 34 feet. This is illustrated in figure 14.

(2) Going up in the air we find that the rate of pressure decrease (pressure lapse rate) is not constant. It will be noted that the pressure is reduced to half (500 millibars) at about 17,000 feet, to 1/4 (250 millibars) at about 37,000 feet, and to 1/5 at about 40,000 feet.

b. Assuming a surface pressure of 1,000 millibars, it is seen that at about 40,000 feet the pressure will be about 200 millibars. The pressure exerted by the oxygen alone at the surface would be 200 millibars and at 40,000 feet only 40 millibars.

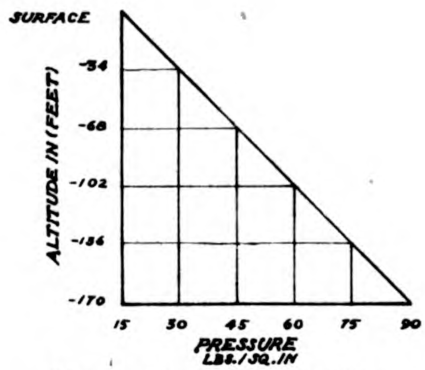


FIGURE 14.—Ocean pressure.

c. The human body functions best with the amount of oxygen supplied under normal pressure, i. e., about 1,000 millibars total pressure or 200 millibars oxygen pressure. An insufficient supply of oxygen results in irreparable damage to the brain. Therefore, flights above 15,000 feet and prolonged flights at 10,000 feet should not be made without oxygen.

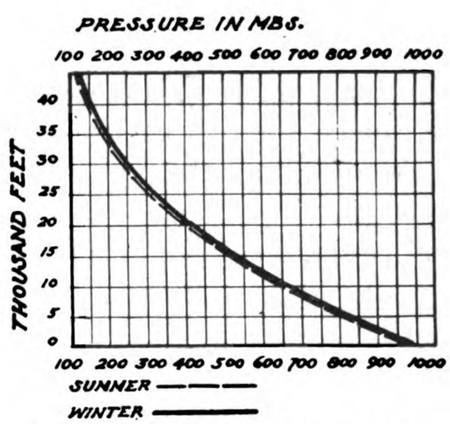


FIGURE 15.—Pressure lapse rate.

d. Properly regulated oxygen supply is such that the oxygen pressure will amount to approximately 200 millibars. This is accomplished by displacing part or all of the nitrogen normally in the air with oxygen. Thus, at about 17,000 feet when the total pressure is about 500 millibars, the proper mixture would be 200 millibars oxygen and 300 millibars nitrogen, or ⅖ oxygen.

e. At 40,000 feet, pure oxygen would have to be used to exert a pressure of 200 millibars. Flight above this level requires some type of pressurized suit or cabin.

28. Altimeters.—*a.* An altimeter is primarily an aneroid barometer, constructed to indicate altitude in feet instead of units of pressure. It will be seen from figure 15 that the pressure lapse is fairly constant up to about 25,000 feet. Therefore, the altimeter can be expected to read fairly accurately at normal flying levels.

b. However, an altimeter can be made to read accurately only under one particular set of conditions; i. e., the so-called standard atmosphere which assumes a certain pressure and temperature at sea level, and a certain temperature lapse rate. Since such standard conditions almost never exist, the altimeter reading usually requires correction.

c. For this reason altimeters are designed so that adjustment may be made to correct for nonstandard surface pressure.

d. Under most operating conditions the simplest procedure is to set the altimeter to read 0 at sea level; i. e., the elevation of the field while on the ground. The altimeter will then read the altitude above

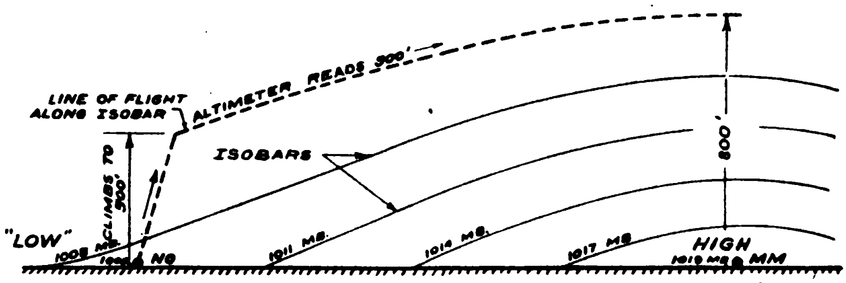


FIGURE 16.—Altimeter correction.

sea level. Airways flying is at elevation above sea level, height of obstacles is given in elevation above sea level, and rendezvous and interception problems are conducted at elevation above sea level.

e. Pressure is frequently different at the point of landing than at take-off. Even though the altimeter were correctly set at take-off, it might be considerably off at time of landing. In landing under conditions of poor visibility or low ceiling, it is essential that the altimeter be set to read the correct altitude. Altimeter setting can be obtained by radio if available. Otherwise, the expected altimeter setting for use when landing should be obtained before take-off. A general idea of the existing pressure system will be helpful if no accurate setting is available.

f. Even though the pilot can determine the correction to be made, he can apply it either the right way or the wrong way. Figure 16 shows the pattern of isobars in a cross section of the atmosphere from New Orleans, Louisiana, to Miami, Florida. The pressure at New Orleans is given as 1009 and the pressure at Miami is given as 1019.

a difference of 10 millibars. A pilot takes off from NO with intentions of flying to MM at an altitude of 500 feet. However, due to an increase of pressure of 10 millibars from NO to MM, he gradually gains altitude and, although his altimeter still reads 500 feet, actually he will be flying at 800 feet over Miami as shown in the figure. The correct altitude can be found by obtaining the correct altimeter setting from Miami then resetting his altimeter.

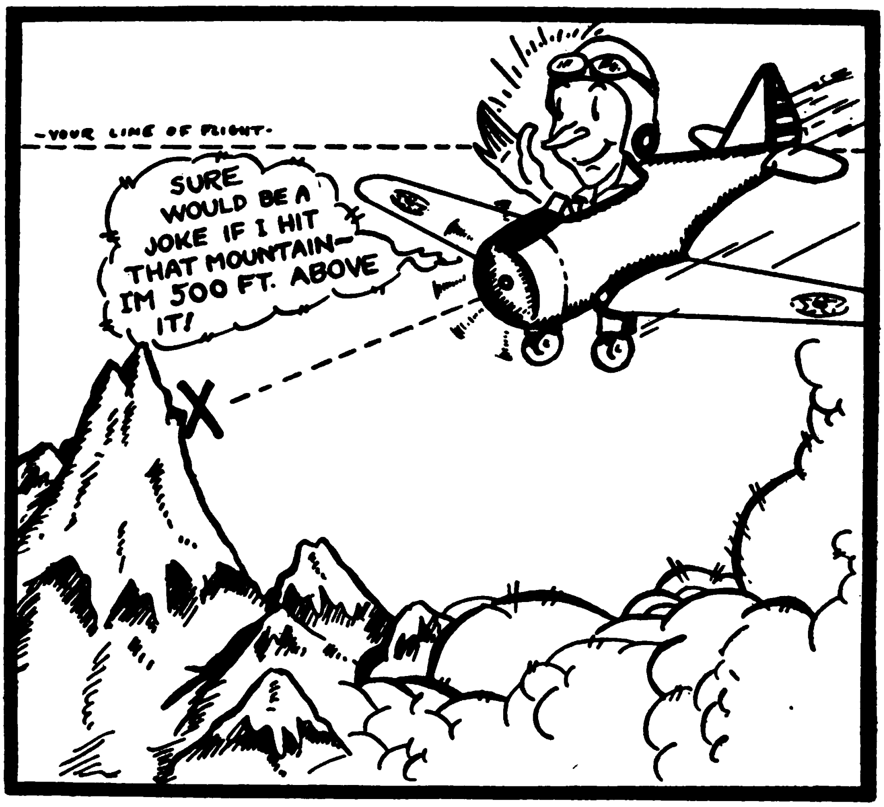


FIGURE 17.—Know your pressure field.

g. Remember that you have to go up to reach lower pressure.

h. Certain relationships should be remembered. These hold generally up to about 15,000 feet.

1,000 millibars=30 inches mercury.
34 millibars=1 inch mercury=1,000 feet elevation.

NOTE.—A change of 10 millibars (which is common) would result in an error of about 300 feet.

i. Another altimeter error is due to nonstandard temperatures aloft. Even though the altimeter is properly set for surface conditions, it will usually not be correct at higher levels.

j. Note in figure 18 that if the air is very warm, the indicated altitude will be greater than the true altitude; but if the air is cold, the indicated

altitude will be less than the true altitude. Many crashes have resulted because pilots flying by instrument in cold weather did not understand this altimeter error and did not allow a large enough safety factor for clearing mountains.

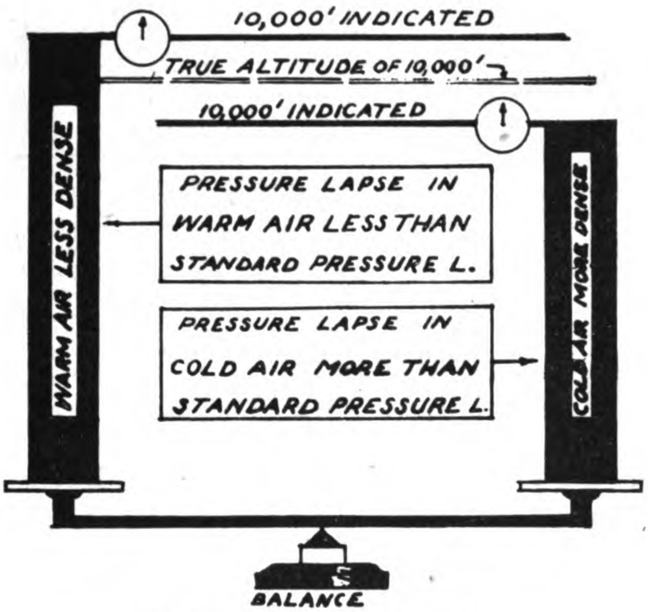


FIGURE 18.—Altimeter error.

29. World pressures.—*a.* It is shown in figure 18 that the pressure lapse is less for warm air than for cold air. Based on the assumption that surface pressure is the same under a column of warm and a column of cold air, it is seen that the pressure at 10,000 feet is *higher* for the warm air than for the cold air.

b. However, surface pressure depends on the weight of the whole column of air above. Assuming that the pressure at 10,000 feet is the same over a column of warm air as over a column of cold air, the surface pressure would be less under the warm air than under the cold, as indicated in figure 19.

c. Reference to figure 20, showing prevailing temperatures and pressure systems over the earth, shows that, in general, relatively cold temperatures are asssociated with high pressure and warm temperatures are associated with low pressure.

QUESTIONS

1. Why is it necessary for the pilot to be acquainted with both the inches of mercury and millibar pressure scales?

2. What is the purpose of reducing observed pressures to a common standard, usually sea level?

3. Define pressure, pressure gradient, and isobar.

4. Explain the relationship between pressure gradient and wind velocity. How is this shown by the position of the isobars on the weather map?

5. What is the normal decrease in atmospheric pressure for each 1000 feet increase in altitude?

6. Why is it impossible to use an altimeter correctly without a knowledge of terrain and the weather map?

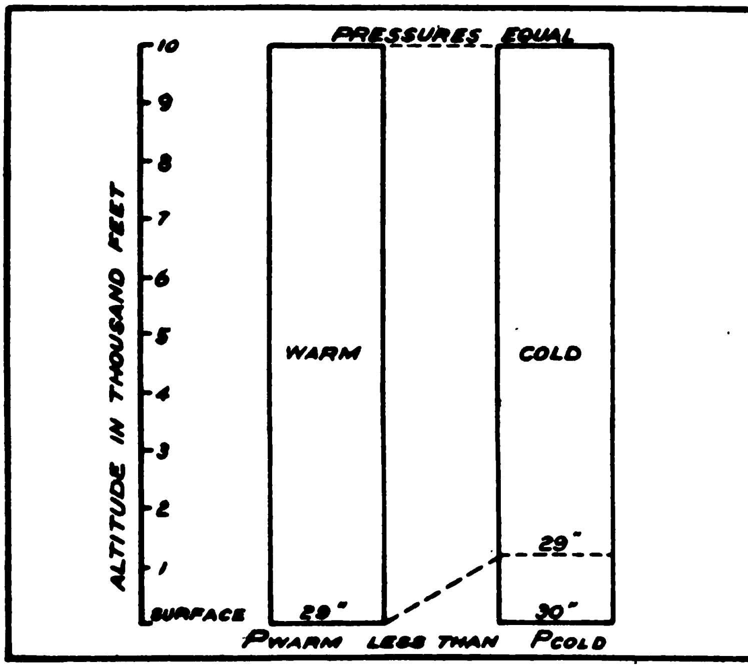


FIGURE 19.—Effect of temperature on surface pressure.

7. On the summer days the land is generally warmer than water. Where would the area of high pressure be located? Give reasons for your answer.

8. Briefly, why is it dangerous to fly at high altitudes without additional oxygen?

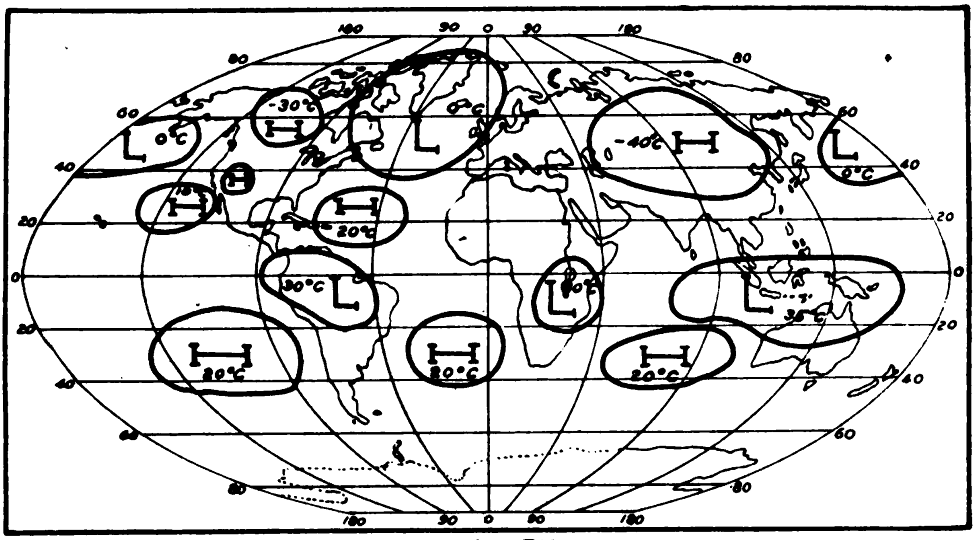
9. In making a routine flight you see from the weather map that your destination is in an area of relatively higher pressure. The trip requires 3 hours.

a. Would your altimeter, on the basis of the morning weather map, read too high or too low at your destination?

b. From the information observed on the weather map would it be advisable to reset your altimeter without additional radio reports? Give reasons for your answer.

10. A pilot takes off on a 4 hour flight that will terminate at his home base. Inasmuch as he is returning to the point of take off is it necessary to reset his altimeter? Why?

11. In relatively cold air would you expect your altimeter to read too high or too low? Give reasons for your answer.



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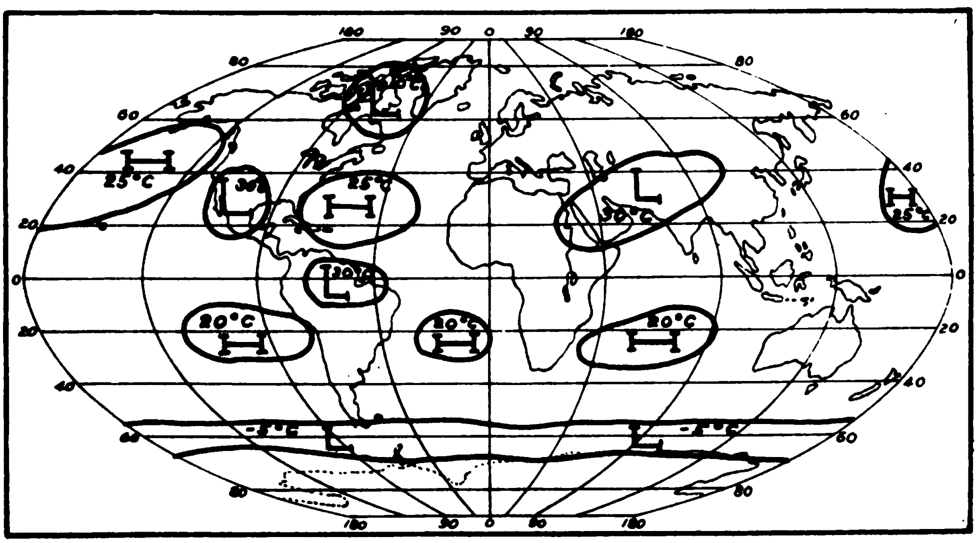

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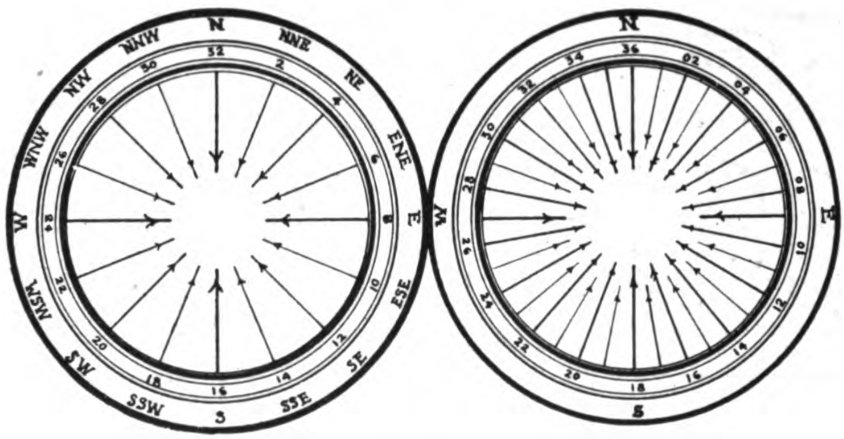
FIGURE 20.—Prevailing temperature and pressure systems over earth.

SECTION IV

WINDS

30. Definition.—Wind is defined as the horizontal movement of air.

31. Measurement.—*a. Direction.*—Wind direction is the direction from which the wind blows, a north wind being a wind blowing from true north. Surface wind reports are made to 16 points of the compass as indicated in figure 21 ①.



① Surface reports. ② Reports aloft.

FIGURE 21.—Wind reports.

(1) On the weather map, the wind direction is shown by means of an arrow flying with the wind. The station circle represents the head of the arrow.

(2) In upper wind reports, the direction is reported in degrees from 0 to 360. Reports are made to the nearest 10°. A wind whose true direction is 343° would be reported as though it were 340°. In the code which is used for reporting upper winds, the last zero is omitted. The wind above would be reported then as 34 instead of 343°. Thus, 90° indicates an east wind and is reported as 09; 180°, a south wind, reported as 18, etc., as indicated in figure 21 ②.

b. Velocity.—(1) Wind velocity on the weather map is shown by the number of barbs on the end of the arrow. Each whole barb represents a Beaufort force of 2 and each half barb a force of 1. Thus represents a west wind of force 5 (about 20 mph). The Beaufort scale of wind force is given in the following table. Note the visible effects of wind of force 4 (15 mph). A pilot should be able to distinguish whether or not the wind is greater or less than force 4.

(2) Upper wind charts show wind direction by means of an arrow through the station circle. The velocity is indicated in numbers alongside the shaft. Thus, $\xrightarrow{52}$ is a west wind of 52 mph.

TABLE II.—*Beaufort scale of wind force*

Beaufort number	Weather map	Velocity mph	General description	Specifications
0		Less than 1	Calm	Smoke rises vertically.
1		1 to 3	Light air	Wind direction shown by smoke drift but not by vanes.
2		4 to 7	Slight breeze	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3		8 to 12	Gentle breeze	Leaves & twigs in constant motion; wind extends light flag.
4		13 to 18	Moderate breeze	Dust & loose paper, small branches are moved.
5		19 to 24	Fresh breeze	Small trees in leaf begin to sway.
6		25 to 31	Strong breeze	Large branches in motion; whistling in telegraph wires.
7		32 to 38	Moderate gale	Whole trees in motion.
8		39 to 46	Fresh gale	Twigs broken off trees; progress generally impeded.
9		47 to 54	Strong gale	Slight structural damage occurs; chimney pots removed.
10		55 to 63	Whole gale	Trees uprooted; considerable structural damage.
11		64 to 75	Storm	Very rarely experienced; widespread damage.
12		Above 75	Hurricane	

32. Why wind?—*a.* People who live near large bodies of water are proud of their cool sea breeze. The reason for the sea breeze is quite simple. Diurnal heating of the land causes a local reduction

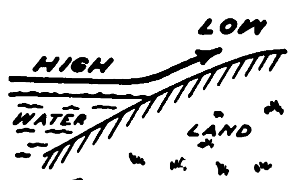


FIGURE 22.—Sea breeze.

of pressure on the land with no corresponding reduction on the water. Therefore, a localized low pressure area is developed, with a pressure gradient from sea to land. Such a gradient is sufficient to

cause the cool sea air to flow inland, going directly from the high to the low pressure as shown in figure 22. However, a sea breeze that is, for instance, from the west at noon will be found to have shifted and be blowing toward the south by evening as shown in figure 23. This shift is caused by the rotation of the earth. (By evening, the air no longer flows directly from H to L.)

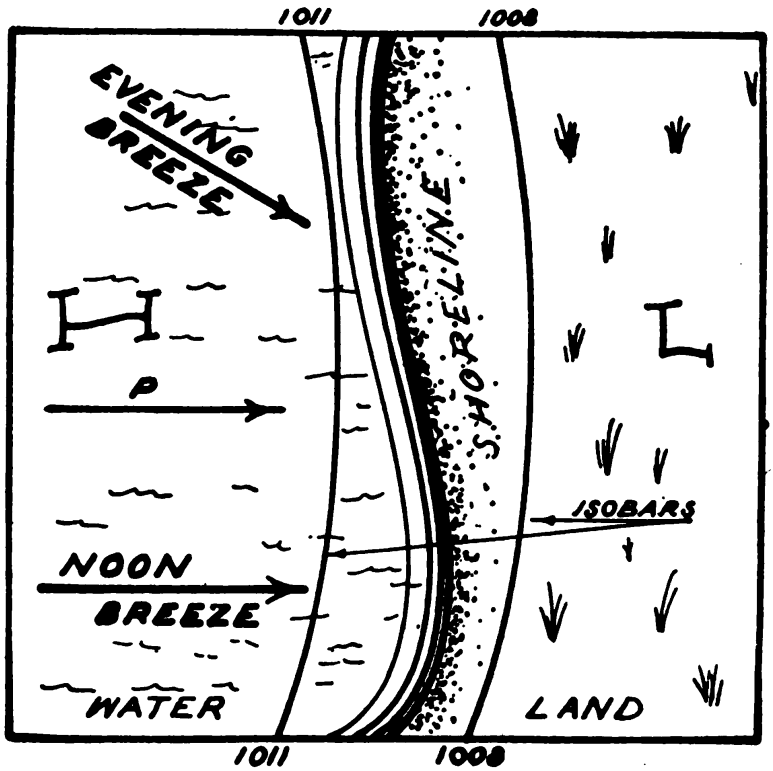


FIGURE 23.—Sea breeze.

b. Reference to any weather map will show that the wind is not directly from high to low pressure, but more parallel to the isobars. If the earth were not rotating, pressures would quickly be equalized by a direct air flow. Actually, pressure systems persist for periods of time ranging from days to months.

33. Coriolis force.—*a*. Due to the rotation of the earth, there is an apparent force acting on any free moving body. This force is called the earth's deflecting force, or, for convenience, the coriolis (pronounced koryolis) force. This force is taken into account in computing range and deflection for the firing of long range guns.

b. The coriolis force is zero at the Equator and greatest at the poles. It always acts to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. It is directly proportional to the velocity of the moving body, zero, of course, when velocity is zero.

34. Forces acting on air in motion.—*a.* Pressure initiates the movement of air. As soon as it begins to move, the coriolis force begins operation to the right in the Northern Hemisphere.

b. The coriolis force continues to the right, becoming equal and opposite to the pressure force as shown in figure 24, which results in a wind blowing parallel to the isobars. Such a wind blowing parallel to straight isobars is called geostrophic wind.

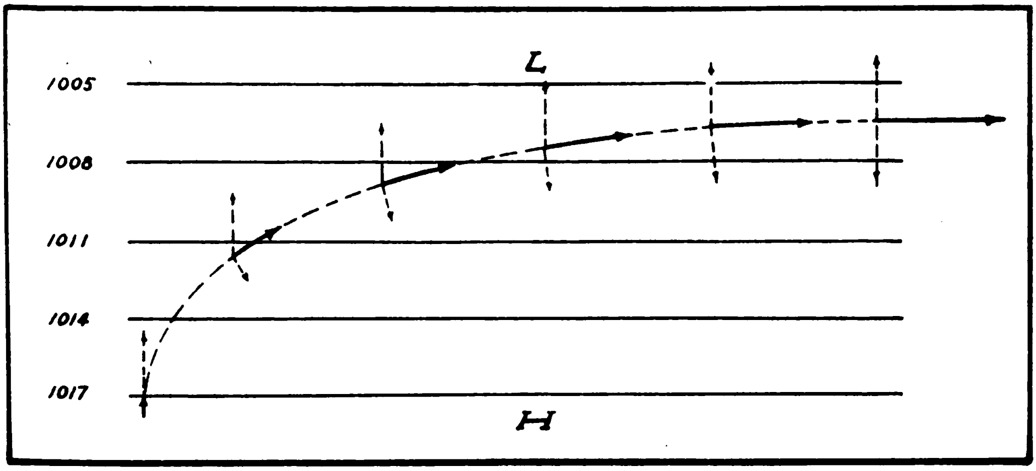


FIGURE 24.—Geostrophic wind.

c. If the isobars are curved (as is normally the case), centrifugal force plays a part. The wind would still blow parallel to the curved isobars, and in such case is called the gradient wind.

d. Winds actually encountered in flight are gradient winds; however, mathematical computations of wind velocities are made only for geostrophic winds. So far as the pilot is concerned these two terms mean the same thing, and are mentioned to prevent confusion to a pilot.

e. The velocity of the wind depends on the intensity of the pressure force, which in turn is shown by the spacing of the isobars on the weather map. Reference to maps will show that the closer the isobars the stronger the wind.

35. Friction.—*a.* As would be expected, force of friction influences air movement, particularly near the surface of the earth. Friction reduces the wind velocity near the surface. Consequently, the coriolis force (which is proportional to velocity) is reduced although the pressure force is still the same and toward low pressure. Thus, the wind observed near the surface of the earth is not parallel to the isobars, but somewhat toward the low pressure as shown in figure 25.

b. Friction, of course, depends on the roughness of the surface, and is least over water, and greatest over rough land. Over average terrain, we can assume that friction will not affect the wind above approximately 2,500 feet. Thus, at 3,000 feet we are safe in assuming the gradient (or geostrophic) wind, both in velocity and direction. At the surface, we may assume that over land the wind will flow across the isobars at about a 30° angle, and at about half the gradient velocity. Conversely, observing the wind at the surface will indicate the wind at higher levels.

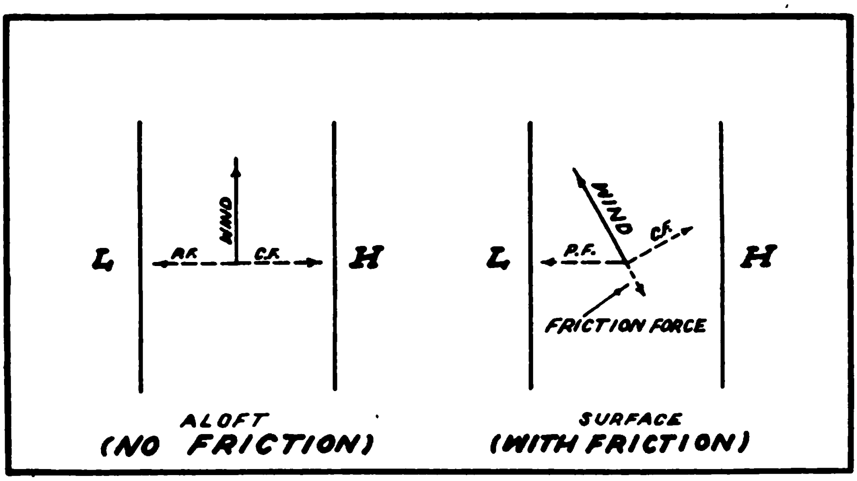


FIGURE 25.—Effect of friction.

36. Prevailing pressure systems and winds.—Observations over many years show that certain pressure systems control the winds in their vicinity, including most of the earth. Winds, in turn, control weather. Figure 26 shows these prevailing systems. However, the pilot should bear in mind that "prevailing" means most of the time, not all the time. Successful pilotage depends on your ability to distinguish the unusual condition, and decide what to do about it before it is too late.

QUESTIONS

1. Define wind.
2. From which direction does a west wind blow?
3. Explain how wind direction and velocity is plotted on the weather map and teletype reports.
4. What determines the direction in which a sea breeze blows? Explain.
5. How does the coriolis force effect the air flow in the northern hemisphere? In the southern hemisphere?
6. Define gradient wind. Where is it found?

7. What is the relationship among isobars, pressure gradient, and wind velocity?

8. Upon what does the amount of friction depend and how does it affect air movement?

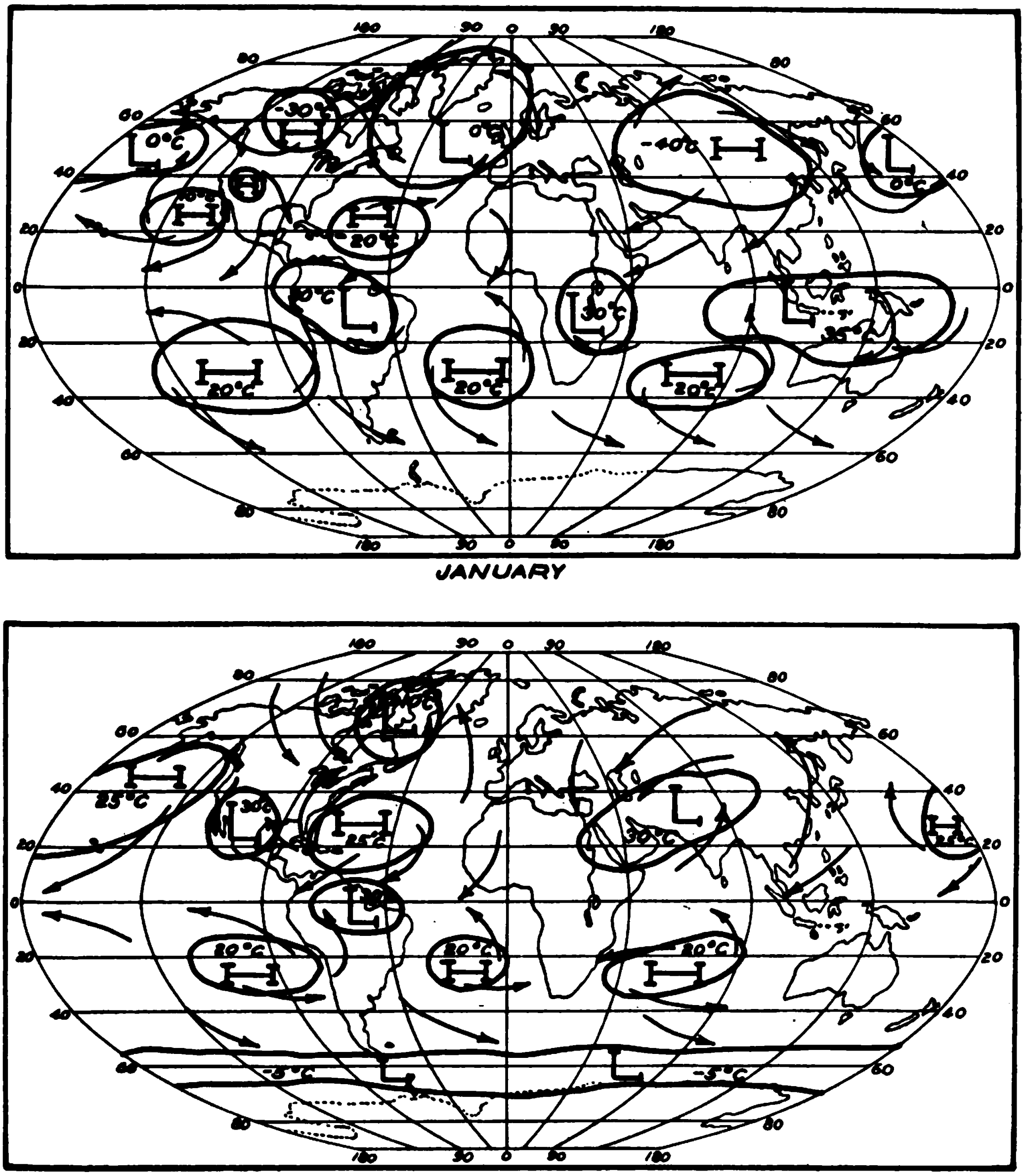


FIGURE 26.—Prevailing winds and pressure systems over the earth.

9. What is the fundamental cause of high and low pressure areas?

10. How is wind direction reported for upper wind observations?

11. Of what value are upper wind reports to the pilot?

12. Why are pressure systems usually maintained for a long period of time?

Section V

MOISTURE IN ATMOSPHERE

37. General.—Practically all weather that interferes with the operation of aircraft is directly associated with water in some form. The physical processes covered in this section may not seem to have much importance to the pilot. However, a clear understanding of this material is essential to the study of weather that concerns a pilot, particularly in regard to one of the most serious hazards to aviation, namely, icing of aircraft.

38. Water vapor in atmosphere.—The most immediate contacts a pilot has with the humidity in the atmosphere is through the daily weather map and on teletype sequences. Above and to the right of a station appear such figures as 73/68. The 73 gives the temperature and 68 gives the dew point in degrees Fahrenheit for that station.

a. Dew point.—The dew point is the temperature to which the air must be cooled to become saturated with water vapor. The sweating of an ice pitcher indicates that it is at or below the dew point temperature for the air in the room. One observes in this simple experiment that there is a definite relationship between the amount of moisture the air can hold and its temperature. When the air can hold no more water vapor and water begins to condense on nearby objects, we say that the atmosphere is saturated with water vapor at that temperature.

b. Water vapor pressure.—(1) A simple experiment illustrated in figure 27 will give a quantitative relationship between the temperature and the pressure of saturated water vapor. The bent tube contains mercury, above which is a little water and water vapor on the left side, and a vacuum on the right side. The mercury column on the right will always be higher than that on the left. This is due to the pressure exerted by the water vapor. The difference in the two columns of mercury is a direct measure of the vapor pressure and is indicated by P. By raising the temperature of the surrounding water bath slowly and observing the corresponding pressures, one obtains the results plotted in figure 28.

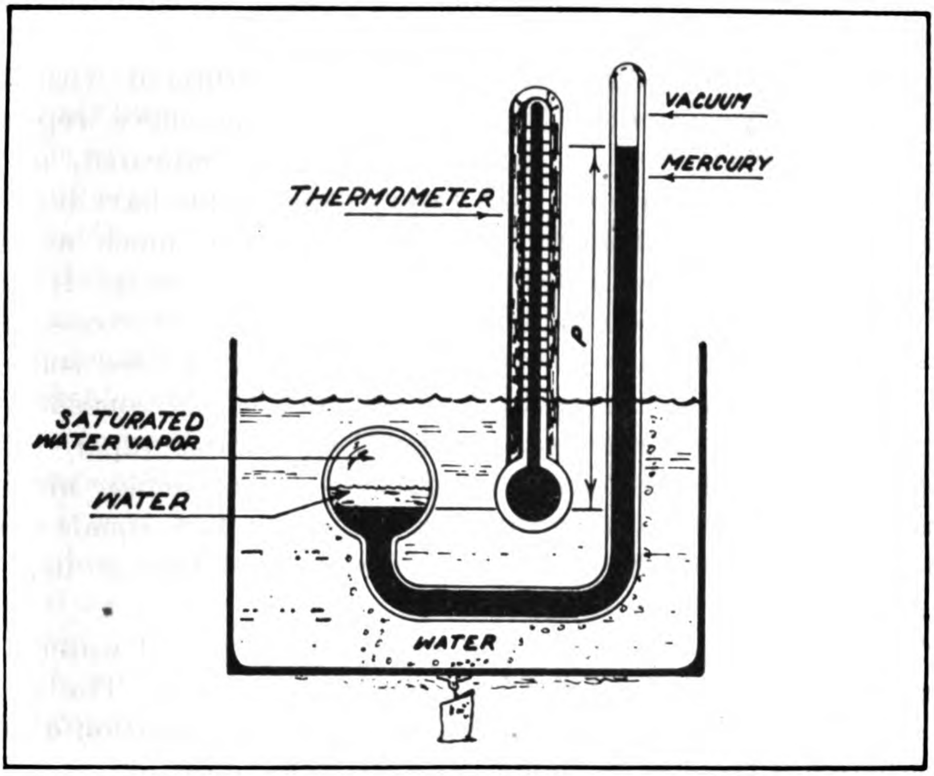


FIGURE 27.—Water vapor experiment.

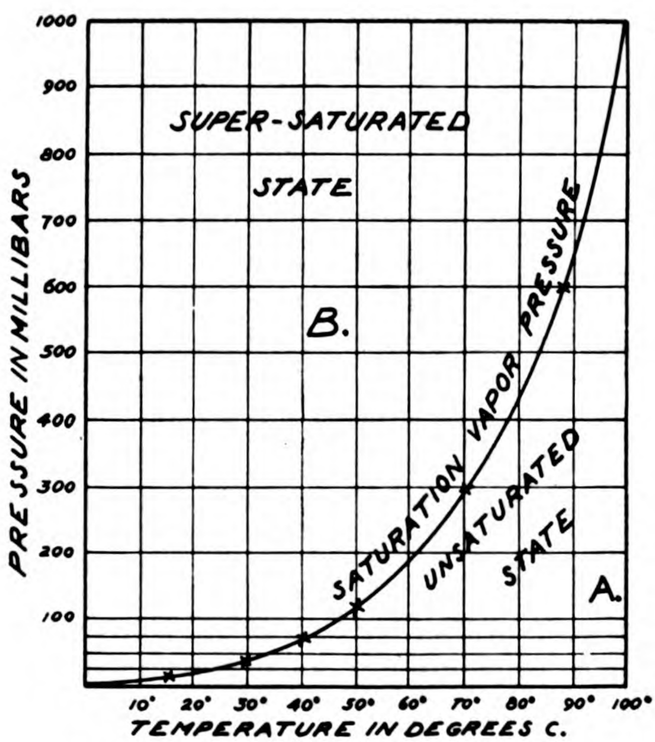


FIGURE 28.—Saturated vapor pressure curve.

(2) This is known as the maximum vapor pressure curve or saturation curve for water vapor. Any condition represented by a point A, to the right and below the curve, would be unsaturated with water vapor, while the point B, to the left and above the curve, represents a state of supersaturation. Supersaturation, as indicated, may be realized at any temperature. Laboratory experiments have been performed where by supersaturation amounting to as much as eightfold have been attained by removing condensation nuclei from the air. However, it is doubtful if relative humidities in excess of 100 percent have even been observed in the atmosphere since condensation nuclei are always present in varying degrees of concentration. Normally, the atmosphere is not saturated with water vapor. Evaporation will therefore continue from any water surface until the partial pressure of the water vapor in the atmosphere equals that of the saturation vapor pressure for a given temperature as indicated by the graph in figure 28.

c. Specific humidity.—The actual number of grams of water vapor in a kilogram of air is defined as specific humidity. The specific humidity is connected to the vapor pressure by the equation $q=0.622\ e/P$, where q is the specific humidity, e the vapor pressure, and P the pressure of the air. It will be noted in the following table that for any particular temperature the air can hold only as much water vapor

TABLE III

Dew point temperature		Saturation vapor over water pressure in millibars	Specific humidity in grams per kilogram
° C.	° F.		
−20	−4	1. 27	. 77
−15	5	1. 91	1. 18
−10	14	2. 86	1. 76
−5	23	4. 21	2. 59
0	32	6. 11	3. 77
5	41	8. 72	5. 36
10	50	12. 28	7. 58
15	59	17. 05	10. 50
20	68	23. 38	14. 40
25	77	31. 68	19. 50
30	86	42. 45	26. 10
35	95	56. 23	34. 60
40	104	74. 10	45. 60
45	113	95. 84	59. 10

NOTE.—These pressures are slightly less over ice than over water. See table IV.

as is indicated. Also, it is apparent that for any given amount of moisture in the air there is a definite saturation temperature. This saturation temperature is called the dew point. For example, in a body of air having a specific humidity of 7.6, saturation will be reached when the air is cooled to 10° C. or 50° F. The dew point temperature of this air is then 10° C. or 50° F.

d. Relative humidity.—It is very important to the meteorologist and to the pilot to know how nearly saturated the atmosphere is at any given time or place, in other words, to know the relative humidity. This is defined as the ratio of the actual amount of water vapor in the atmosphere to the amount it could hold if it were saturated. This ratio is expressed in percentage. As an example, suppose the air were at a temperature of 20° C. and contained 7.58 grams per kilogram. It could hold 14.4 grams per kilogram if it were saturated. The relative humidity would therefore be 7.58/14.4 or 52 percent. If the temperature were reduced to 10° C., the air would become saturated and condensation would begin to take place. Ten degrees centigrade is therefore the dew point for this air. At ordinary temperatures the air approximately doubles its ability to hold water vapor for each increase of 10° C. in its temperature.

e. Instruments.—(1) Relative humidity is usually measured with a hair hygrometer which operates on the principle that oil-free human hair stretches upon being wet and the stretch is proportional to the degree of saturation of the air with water vapor, or upon its relative humidity. The hair is mounted under tension to operate a dial which indicates, or a pen which records, the relative humidity directly.

(2) The Sling psychrometer, or wet and dry bulb hygrometer, consists of two thermometers, one of which is kept wet by a wick provided for that purpose. The cooling of the wet bulb thermometer is proportional to the rate of evaporation of the water from it, which, in turn, depends upon the moisture content of the atmosphere. When the atmosphere is very dry, the depression of the wet bulb temperatures is large. When the air is saturated, there is no evaporation and the thermometers read the same temperature. Psychrometric tables are provided which enable one to obtain the dew point and the relative humidity from the air temperature given by the dry bulb and the temperature given by the wet bulb.

f. Distribution of water vapor.—That part of the atmosphere which remains over tropical water may contain large amounts of water vapor, for example, up to 40 grams per kilogram, and because of its high temperature it will not be completely saturated. On the other hand, air from the polar continental regions may have a specific

humidity of less than 1.0 and because of the low temperatures found in these regions may be saturated and have precipitation falling. The weight of the water vapor in the atmosphere, when it holds its maximum quantity, is rarely more than 4 percent of the total.

39. Three states of water.—*a.* The pilot encounters water in the atmosphere in any one or two or all three of its physical states, namely, as gas, liquid, and solid; or, as vapor, cloud or rain, and ice. The

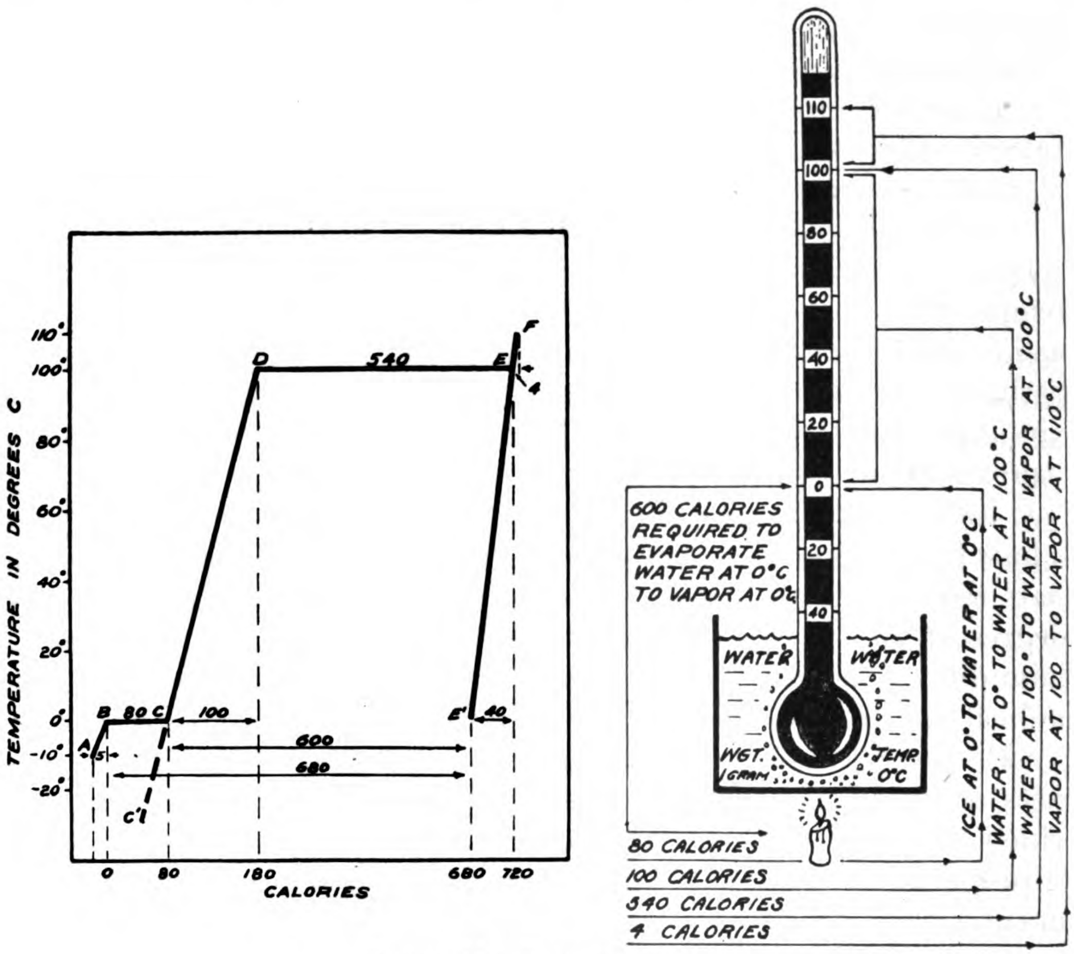


FIGURE 29.—Energy changes.

essential differences in these three states of water is one of energy content more than one of temperature. The following energy diagram of figure 29 will indicate these differences. Picture the point A on the energy diagram as representing a gram of ice at −10° C. and being heated until it becomes water vapor at 110° C.

b. The heat involved and the processes taking place are as follows:

(1) *Specific heat of ice.*—The temperature of the ice would first be raised to 0° C. by absorbing 5 calories of heat. A calorie has already been defined as the heat required to raise the temperature

of 1 gram of water 1° C. Since the specific heat of ice is only .5, it requires 5 calories to raise this gram of ice from −10° C. to 0° C. This is represented on our energy chart by the line AB.

(2) *Latent heat of fusion of ice.*—Upon further addition of heat the temperature remains constant at 0° C., but the energy is absorbed to melt the ice; i. e., change it from a solid to a liquid state. Eighty calories are needed to melt a gram of ice and this energy is known as the latent heat of fusion of ice. The line BC represents this physical change.

(3) *Change to boiling point.*—To raise the temperature of the water from its freezing temperature at 0° C. to its boiling temperature at 100° C. requires 100 calories of heat. In this case, line CD shows that both energy and temperature increase.

(4) *Heat of vaporization and condensation of water.*—Five hundred forty calories of heat are now added to evaporate the water or to change it from a liquid state to the vapor state without changing its temperature of 100° C. The line DE is not drawn proportional to the energy which it represents, but it indicates the enormous amount of heat involved in effecting this change of state.

(5) *Specific heat of water vapor.*—The water vapor can now be raised to any higher temperature by assuming the vapor to occupy a constant volume and adding the necessary amount of heat. The specific heat of water vapor is about .4. It would, therefore, require 4 calories to raise the vapor from 100° C. to 110° C., assuming the volume to remain constant. In case the reverse process takes place, i. e., the temperature is reduced, then these same quantities of heat are released to the surrounding atmosphere.

(6) *Heat of condensation at normal temperatures.*—If evaporation takes place from the liquid surface at 0° C., approximately 600 calories of heat are required to effect this change of state. Conversely, if condensation takes place and 1 gram of water vapor is condensed into 1 gram of liquid water, the same number of calories of heat are released. CE′ represents this change on the energy diagram. Practically all the condensation that occurs in the atmosphere takes place between the temperatures of 30° C. and −30° C. and 600 calories is accepted as the round number figure for the heat given off in the process. This value will therefore be used throughout this course as the condensation heat of water vapor.

(7) *Sublimation.*—It is known that a solid can pass directly into a gaseous state upon addition of heat without first going through the intermediate liquid state. This process is known as sublimation. Camphor, iodine, and ice are classic examples of this process. This

is shown on the energy diagram by the line BE′ representing 680 calories. The heat of sublimation of ice, the amount of heat required to change 1 gram of ice into 1 gram of water vapor at 0° C. or the heat given off when the reverse process takes place, is 680 calories.

(8) *Supercooled water.*—The extension CC′ of the line DC represents liquid water in a supercooled state, or at temperatures below freezing. It is a very common occurrence for liquid water in the form of fog, cloud, mist, drizzle, and rain to exist in the atmosphere at subfreezing temperatures. Liquid water fogs have been observed in Greenland at −34° C., and in Little America as low as −44° C. This apparently unnatural condition plays a very important role in the phenomena of condensation, precipitation, and icing going on continuously in the atmosphere. They will be treated in detail at appropriate points in the course.

(9) *Summary.*—From the foregoing discussion one will note that water can exist in the atmosphere at standard pressures as a solid, liquid, or vapor; at temperatures below 0° C.; as a liquid or a vapor at temperatures between 0° C. and 100° C.; and only as a vapor at temperatures above 100° C. The density of the saturated vapor and its corresponding vapor pressure will be determined at all times by its temperature as indicated by the graph in figure 28.

40. Changes of state processes.—The foregoing discussion of figure 29 contains an elementary explanation of the energy transformations that must accompany any and every change of state experienced by the three forms of water in the atmosphere. Just how these processes of evaporation, condensation, and sublimation take place can best be described by reference to the following sketches representing molecular transfer from one phase to another.

a. Evaporation and condensation.—Figure 30 ① represents a pan of water at temperature T. Above the liquid surface AB is the atmosphere, saturated with water vapor at temperature T′. If T equals T′, there will be as many molecules (represented by the arrows in the diagram) leaving the liquid per unit of time as there will be returning to it. The evaporation will be balanced by the condensation. If T is greater than T′, the evaporation will exceed condensation, resulting in a net increase of water vapor for the air. This increase may be enough to saturate the air and cause fog or clouds to form. If T is less than T′, more molecules will return to the liquid state than leave it, and condensation will be greater than evaporation. This process may cause dew to form.

b. Sublimation.—(1) It is known from energy considerations that it takes more work to transfer a molecule from the solid state to the

vapor state than from the liquid state to the vapor state. Consequently, at the same subfreezing temperature, fewer molecules would have sufficient energy to free themselves from the solid state and sublime into the atmosphere than could free themselves from the liquid state or evaporate into the atmosphere. A state of equilibrium would be established between the three states as illustrated in figure 30 ②.

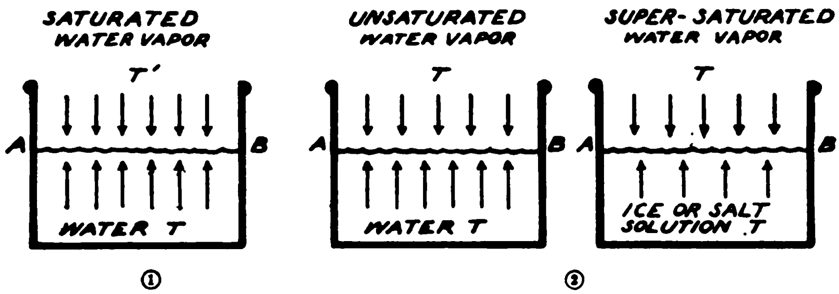


FIGURE 30.—Changes of state processes.

While six molecules are evaporating from the water surface only four will sublime from the ice surface. Theory requires that the vapor pressure over water at subzero temperatures be greater than over ice, and experiments have verified this conclusion. A few values are given in the following table:

TABLE IV

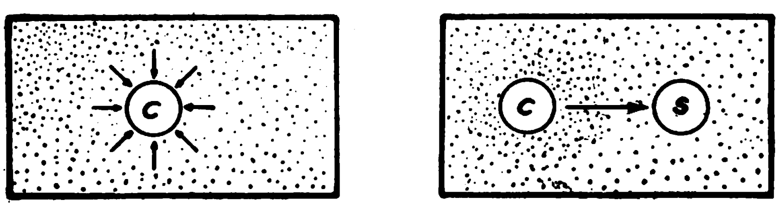
Temperature in ° C	−5	−10	−15
Vapor pressure over water in millibars	4. 21	2. 86	1. 91
Vapor pressure over ice in millibars	4. 01	2. 60	1. 65
Difference in millibars	. 20	. 26	. 26

(2) The atmosphere which has adjusted its vapor pressure to a mean value somewhere between that over the two surfaces is unsaturated for the liquid phase and supersaturated for the ice phase. There will be a gradual transport of water through the medium of water vapor from the liquid state to the solid state. This process of evaporation from the liquid drops and sublimation on ice crystals furnishes the best explanation of the growth of raindrops sufficiently large to result in precipitation at the earth's surface.

(3) Bergeron has arrived at the conclusion that in the average cloud there are 4.2×10^{-6} grams of liquid water per cubic centimeter distributed among 1,000 droplets of 20-micron, 0.02-mm diameter. (A micron equals $\frac{1}{1000}$ millimeter.) In the same space there is one ice crystal. It would require from 10 to 20 minutes to transfer

all of the water droplets by the above process to the ice crystal. It would fall through the cloud below as a solid particle 200 microns in diameter adding to its size all smaller drops it touched in its path and coalescing with other crystals. Its lower temperature would cause further condensation upon it in the warmer cloud regions below. Upon emerging from the base of the cloud the solid particle would continue falling to the earth as snow or hail if it were in the winter, and as rain if in the summer time when the lower atmosphere temperatures would be high enough to melt it.

c. Condensation and sublimation nuclei.—(1) The difficulty with which salt is removed from its container in the damp weather is due to the high affinity of salt for water vapor. The phenomenon is the same for salt at any temperature as for ice at temperatures below freezing. As the process continues, sufficient water would be accumulated to dissolve the salt grain but the drop solution thus formed would always maintain about it a vapor pressure less than the saturated air. It would, therefore, grow in size and dilution until an equilibrium were established between it and the surrounding atmosphere.



① Condensation nucleus in saturated water vapor.

② Condensation and sublimation nuclei in saturated water vapor.

FIGURE 31.

(2) The most efficient condensation nuclei known are the sulphur and phosphorous products of combustion and the salt spray blown into the wind action over the ocean. They form hygroscopic nuclei into which water vapor rapidly condenses when it reaches the saturated state. Figure 31 ① illustrates the process of forming liquid drops. But it is agreed that liquid drops alone cannot result in anything more than a cloud, fog, mist, or drizzle, whose maximum size drops are less than 0.5 mm in diameter. To have rain drops requires the presence of sublimation and condensation nuclei, involving the process illustrated in figures 30 ② and 31 ② and discussed in former paragraphs.

41. Formation of a cloud.—The moisture in the atmosphere at the surface is generally insufficient to saturate it and form a cloud. There must be some cooling process by which the dew point is reached

and condensation takes place. There are three important methods by which this cooling takes place.

a. Advection.—When warm moist air is blown over colder land or water areas, particularly those covered with snow and ice, the air may be cooled to the dew point temperature, and fog or low stratus clouds result.

b. Radiation.—Water vapor radiates heat very well to outer space, and this results in a temperature drop after the sun goes down. If the atmosphere is sufficiently humid, the dew point may be reached by this process and clouds appear and remain until the heat of the sun warms the air and dissipates the clouds the next day.

c. Adiabatic.—An adiabatic process is one in which a change takes place in a substance without the addition or subtraction of heat. When a gas is compressed, work is done upon the gas; this work appears as thermal energy in the compressed gas and its temperature goes up. The heating of a pump when inflating an automobile tire or the heat radiating system in a refrigerator are good examples of adiabatic heating by compression. When the valve is removed from an automobile tire, one feels the adiabatic cooling effect in the escaping air. In this case, the expanding air has done work in pushing back the atmosphere to make room for itself. The only source of this energy must come from the internal thermal energy contained in the expanding air and its temperature will be reduced. Since no heat is either added or subtracted in the above examples, they are all adiabatic processes.

(1) *Dry adiabatic lapse rate.*—(*a*) Whenever a parcel of dry air is made by wind action to move up the slope of a mountain, its pressure will be continuously reduced. It will expand doing work against the surrounding air and since no heat is added from its surroundings, the process will be adiabatic and its temperature will be lowered. In the free atmosphere the volume of the rising air parcel will increase proportionately as the pressure decreases, and the temperature will decrease at an average amount known as the dry adiabatic lapse rate. Its value is given in the following table.

TABLE V.—*Adiabatic lapse rate*

Dry rate per 1,000 feet	Wet rate per 1,000 feet (average rate)
3° C.______	1.5° C.
5.5° F.____	2.8° F.

(*b*) If the air parcel in figure 32 ② were at a surface temperature of 15° C. and were forced to the top of a 10,000 foot mountain, its temperature would be lowered 3° x 10 or 30° C. and it would appear at the top with a temperature of −15° C. This, of course, is true if throughout this distance. When the air descends upon the leeward side of the mountain, the adiabatic compression would warm it up exactly the same number of degrees and it would arrive at the zero level at plus 15° C.

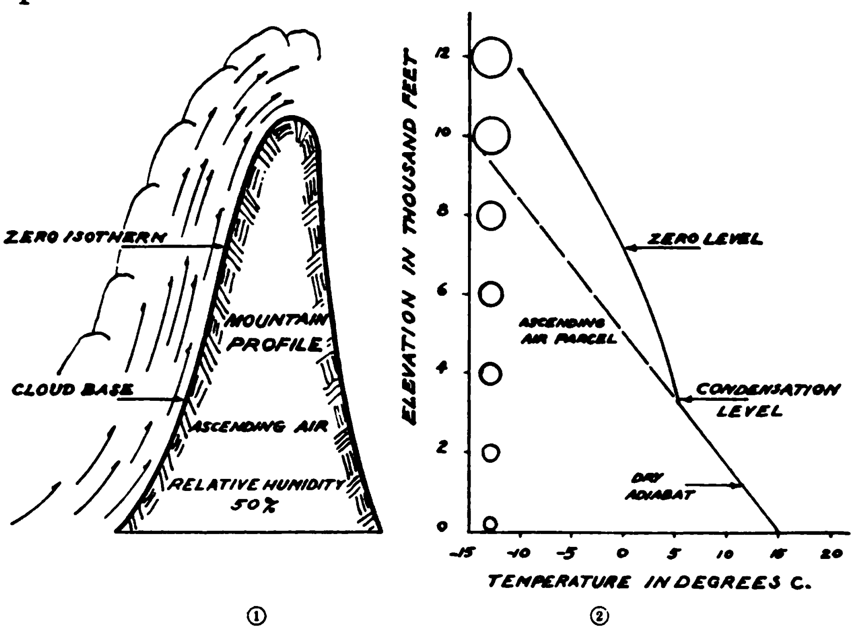


FIGURE 32.—Adiabatic expansion.

(2) *Wet and dry air.*—The atmosphere is spoken of as being dry when the relative humidity is less than 100 percent, and as wet, moist or saturated when the relative humidity is 100 percent. When saturated, condensation occurs which results in the formation of clouds.

(3) *Condensation level.*—It is only very, very dry air with a relative humidity of or near 10 percent that could be lifted 10,000 feet without forming a cloud. Normal air in the free atmosphere generally has a relative humidity above 30 percent. If we assumed the air parcel at the zero level and at 15° C. had a relative humidity of 50 percent, then when it had been lifted sufficient to cool it adiabatically 10° C., condensation would begin and the base of a cloud would appear. In figure 32 ② this would be realized at an elevation of 3,300 feet, and is known as the condensation level.

(4) *Wet adiabatic lapse rate.*—Above the condensation level, water vapor is continually being condensed into liquid water by the process previously discussed and for each gram of water vapor condensed into liquid water, 600 calories of heat are given off into the atmosphere.

This added heat would naturally slow down the adiabatic cooling process, the amount depending upon the quantity of water condensed. In the lower atmosphere where the temperature and the specific humidity are high, condensation would be rapid, the heat evolved would be large, and the wet adiabatic lapse rate would be small. Higher in the atmosphere, where the temperature and specific humidity are low, there is little moisture to condense; therefore, little heat is given off to the atmosphere, and the wet adiabatic parallels the dry adiabatic, or the wet adiabatic lapse rate approaches the dry adiabatic lapse rate. In the layers of the atmosphere used most frequently by the pilot, the wet adiabatic lapse rate is about one-half that of the dry adiabatic lapse rate and is given in table V. Because of this added energy from condensation, the zero temperature level is reached at about 8,000 feet, or, 3,000 feet higher than if the air had remained unsaturated up to the zero level.

42. Precipitation.—*a.* In figure 32 ② one will note that below the cloud base only water vapor is present in the air. Between the cloud base and the zero isotherm, water vapor and liquid water drops are present. Above the zero isotherm, water vapor, liquid water, and ice crystals can be present; the last two in varying degrees of concentration, but the water vapor only in quantities determined by the temperature as indicated by table III.

b. Water clouds cannot produce precipitation in any great quantity since there is no means by which large drops can be produced in them. They may yield mist and drizzle, which may reach the surface of the ground if the condensation level is sufficiently low and the relative humidity of the unsaturated air below is high enough to retard evaporation.

c. The development of real precipitation can come about only in the upper or higher levels of the cloud, well above the zero isotherm which appears in figure 32 near 8,000 feet. Above this level a few water drops may freeze to form a solid particle upon which sublimation will take place, or there may be some sublimation nuclei or ice crystals floating in the atmosphere as residue from older ice clouds above. If the air is forced to high elevations by orographic lifting, a seemingly critical temperature is reached between −15° C. and −20° C. at which crystallization takes place very rapidly, resulting in a sudden transfer of water from the supercooled water droplets to the ice particles. The particles grow to a size above which the pull of gravity is greater than the sustaining force of the ascending air currents and the particle will fall. It collides with smaller solid particles and liquid drops that coalesce into a still larger drop. At

the same time water vapor is subliming on its surface because of the temperature differential which now exists between the cold ice particle rapidly descending from above and the warm, saturated air below. These large particles may not melt below the zero boundary and may appear at the earth as hailstones. If the ascending currents are light, only small hailstones and graupel are formed which soon melt below the zero degree isotherm and yield rain. At the beginning of the rain shower only the larger drops reach the ground, the smaller ones are evaporated into the warmer and drier air. However, this continued moistening process makes evaporation less rapid until the smaller drops are finally able to reach the surface and the normal shower precipitation occurs.

d. It will be noted that a pilot in his plane will experience very different precipitation conditions in and under the cloud than will be present on the earth. He may be in relatively heavy precipitation where there is no evidence of it at the surface.

QUESTIONS

1. Define dew point, specific humidity, and relative humidity.
2. Give two ways in which we can saturate the air.
3. What is the relationship between relative humidity and saturation?
4. Give the different states in which water might appear in the atmosphere. What is the essential difference among them?
5. Why should the pilot concern himself with moisture in the atmosphere?
6. Define specific heat. What is the specific heat of water vapor?
7. If we have two grams of ice at −10° C., how many calories of heat will be required to convert it into water vapor at 0° C.? at 100° C.?
8. We have air at a temperature of 60° F. that has a relative humidity of 50 percent. If we lower the temperature to 42° F. what will be the relative humidity? If we lower the temperature to 51° F. what will be the relative humidity?
9. In changing the state of water in the atmosphere do we change the temperature? Discuss briefly.
10. What is meant by evaporation? At what temperatures might it occur?
11. When dry air rises, at what rate does it cool? Moist air?
12. Why is there a difference between the dry and moist adiabatic lapse rates?
13. Approximately how high would surface air have to be forced aloft to be cooled to 0° C., if the surface temperature is 24° C. and the condensation level is at 4,000 feet?

SECTION VI

CLOUDS

43. Clouds and weather.—*a.* Clouds are responsible for almost all weather that interferes with the operation of aircraft as well as all the major hazards. Clouds are like store signs, or like the engine instruments. They tell you what to expect inside. Knowing how to read these signs is invaluable knowledge to the pilot.

b. The major problem of the pilot is to decide what to do when the unexpected is encountered and necessitates a change in plans. Malfunctioning of the engine may necessitate a change. Knowing how to interpret your engine instruments in the light of what is going on inside the engine will indicate the action you should take. It is not smart to wait until the engine quits before you decide on a change in your plans.

c. Knowing the meaning of clouds is just as valuable. A smart pilot will read the signs, and not go barging blindly into a situation that he is not equipped to handle.

d. This section deals with individual clouds. However, the major portion of the following sections deals largely of the association of clouds with weather.

e. The student should bear in mind that it is not always desirable to avoid clouds. In wartime flying it is often very advantageous to use the cloud for concealment. If the enemy cannot see you, he cannot shoot you. Consider clouds not only in the light of what should be avoided, but also in the light of what can be used for concealment.

44. Estimates of weather.—*a.* The pilot in the airplane has three things he can use to estimate the weather situation: his temperature gage, bumps, and clouds. Clouds give by far the best indication. The following example will point out the possible use of cloud observations.

b. Suppose you are going out on a long bombardment mission, with a general overcast from 3,000 to 5,000 feet. For the sake of concealment you want to fly in the clouds. However, while you are

in the clouds you cannot see the cloud form, and you might run into something entirely unexpected, such as a thunderstorm. The smart pilot will periodically get out in the clear for a long enough time to see what is going on. Go below the overcast once in a while, and see what is happening below. Go above, and have a look around. The visibility will usually be good on top. You may see a thundercloud ahead. It may stretch from a little to the right of your course to as far as you can see on the left. Then, a slight variation in your flight path to the right will take you around the storm.

FIGURE 33.—Always in trouble.

c. Suppose you had not gone up and looked. You would maintain your course until you noticed a drop in temperature, associated with increasing bumpiness. If you tried then to go up to have a look, you would find yourself in the thundercloud and could see nothing. The only thing to do would be to go back and then look, but you might get into trouble before you could get out of the storm.

d. Trying to view the situation from below is usually not satisfactory due to the restricted visibility generally found below an overcast. Lightning might be seen ahead, but visibility might not be good enough to see where to go to avoid trouble. You might go to the left instead of the right and find that there were no breaks to go through.

e. A little foresight and a good look from above would give a very simple solution in the above case. Lack of foresight and a good look would result more than likely in an unsuccessful mission.

45. Classification of clouds.—Clouds are classified according to composition, form, and international (type and height) classification. The international classification is used universally and is the classification employed on all weather reports and on weather maps. Consequently, the pilot should be familiar with it. The name of the cloud itself means nothing to the pilot unless he can associate the name with the weather indicated by that cloud. Weather is determined primarily by the cloud form and composition.

46. Composition.—A cloud may be composed entirely of water droplets, entirely of ice crystals, or of both water droplets and ice crystals. Since a military pilot must give consideration to the advisability of flying within clouds, it is important for him to know where to expect the clouds of different composition, and how the composition will affect his flying of the airplane.

a. Water cloud.—Any cloud which is entirely in air having a temperature above freezing is a water cloud. Since the air temperature is above freezing, there is no danger of icing.

b. Ice cloud.—Any cloud which is entirely in air having a very low temperature is an ice cloud. Such clouds are composed entirely of ice crystals as, for example, the very high (cirrus type) clouds. There is no possibility of icing in such a cloud, but due to the very high altitude at which they are usually found, only specially equipped airplanes can fly at these altitudes.

c. Ice and water clouds.—(1) Any cloud which is entirely in air having a temperature below freezing and composed of supercooled water with or without ice crystals is an ice and water cloud. The fact that is important to the pilot is not so much whether ice crystals do exist as the fact that this air contains water particles in a liquid state at temperatures below freezing. The supercooled water when agitated by contact with the airplane will freeze and ice will form.

(2) A large cloud may be composed of both water droplets and ice crystals if the bottom of the cloud is in temperatures above freezing and the top of the cloud is in temperatures far below freezing at very high altitudes. Such a cloud may be considered to be composed of three different clouds: a water cloud which exists in temperatures above freezing and is composed entirely of water droplets; an ice cloud which exists in temperatures far below freezing and is composed entirely of ice crystals, and the intermediate part which exists in

temperatures slightly below freezing and is composed of both supercooled water droplets and ice crystals.

(3) The actual temperature at which all the liquid droplets in a cloud will crystallize without mechanical agitation is not definitely established, but appears to be somewhere around −30° C. Therefore, flying in any cloud at any temperature between 0° and −30° C. may result in the formation of ice on the airplane. Flying into any such cloud will present some hazard. The extent of hazard involves other factors which will be brought out in later sections.

47. Form.—*a.* Clouds are commonly observed in two main forms, namely, sheet form or stratiform clouds, and heaped form or cumuliform clouds. Strata means layer; thus stratiform clouds are layer clouds. Stratiform clouds cover large areas usually extending hundreds of miles. Cumuliform clouds are patchy and localized, covering small areas anywhere from a few hundred feet to 50 or 75 miles.

b. Other clouds sometimes appear as a combination; i. e., stratified cumuliform clouds. Such clouds usually represent a transition from cumuliform to stratiform or vice versa. Where true cumuliform appear they are scattered except as noted in the next paragraph. Strata-cumuliform may be broken.

c. Cumuliform clouds may also grow out of a stratiform cloud deck. When this happens, a particularly hazardous condition may result owing to the fact that the pilot may encounter unexpected weather with very little or no warning.

d. A cloud will form whenever the temperature reaches the dew point; i. e., whenever the relative humidity is 100 percent or the air holds all the water vapor possible at that temperature. This may occur at the surface of the earth, in which case fog is formed. This may also occur at other altitudes above the surface of the earth, in which case a cloud is formed.

e. Generally, clouds result from cooling of the air to the dew point temperature. As previously mentioned, there are three main ways in which air may be cooled: by radiation, by advection (air flowing over colder surface), and by adiabatic cooling due to air rising to regions of lower pressure. The advecting cooling is important in fog formation, but not in cloud formation, so the present discussion will be limited to radiation and adiabatic cooling.

f. Before going further into cloud formation, let us consider a few of the things we already know. We know that flying is sometimes smooth. This means there are practically no up or down air currents. Sometimes flying is very rough. This means that there are rather

strong up and down currents. Briefly, then, we know that sometimes there are strong up-currents, and sometimes there are not.

g. We also know that radiation is a rather slow and a steady process. We know, too, that dry (unsaturated) air will cool at the rate of 3° C. per each 1,000 feet if it is lifted. Whether this adiabatic cooling is fast, or slow and steady depends entirely on the rate at which the air goes up. Air moving up a gentle slope, as in the Great Plains area of the United States, will be cooled adiabatically, but slowly. Air blown up the western slopes of the Rocky Mountains may be cooled very rapidly.

h. Also, air sometimes moves upward of its own accord due to a temperature distribution which renders the air unstable. Such movement is fairly rapid, and results in rapid cooling of the air. The more rapid cooling, caused either by raise of air due to rapid force lift or to its own instability, usually results in cumuliform clouds.

i. Slow cooling usually involves air over a wide area whether by radiational cooling or by adiabatic cooling caused by gradual lift. Such cooling usually results in stratiform clouds.

48. Stratiform clouds.—*a.* Due to the factors mentioned in the previous paragraphs, stratiform clouds form as sheet clouds, usually over a large area. They form as stratiform clouds because there are practically no upward currents. The form of the cloud itself shows this fact. The bottom of the cloud is smooth, and fairly level, and the pilot knows that the top is also rather smooth. If vertical currents were present, at least the top of the cloud would not be smooth, but would bulge where the upward currents extend the cloud to higher levels.

b. The lack of vertical currents is characteristic of stable air. Thus we may associate the words stratiform, sheet, smooth, and stable.

c. Precipitation may or may not fall from stratiform clouds, or it may fall from the cloud but evaporate before it reaches the ground. The size of the raindrops depends upon the velocity of the upward currents—the stronger the upward currents, the heavier and larger the raindrops must be before they will fall toward the earth. The precipitation from stratiform clouds, therefore, will usually consist of small drops because of the lack of strong upward currents. Due to the stability and uniformity of the air, the precipitation will be uniform and steady over a large area. Therefore, steady, light precipitation or drizzle is usually associated with stratiform clouds. However, once in a while a very thick stratiform cloud may develop which may result in moderate precipitation with fairly large drops.

d. A stratiform cloud composed entirely of water droplets at temperatures above freezing offers ideal concealment except, of course, when it is so low that there is danger of running into obstacles.

e. A stratiform cloud composed of ice crystals would offer suitable concealment, but most airplanes are not built or equipped to fly at the very high levels at which such clouds would be found.

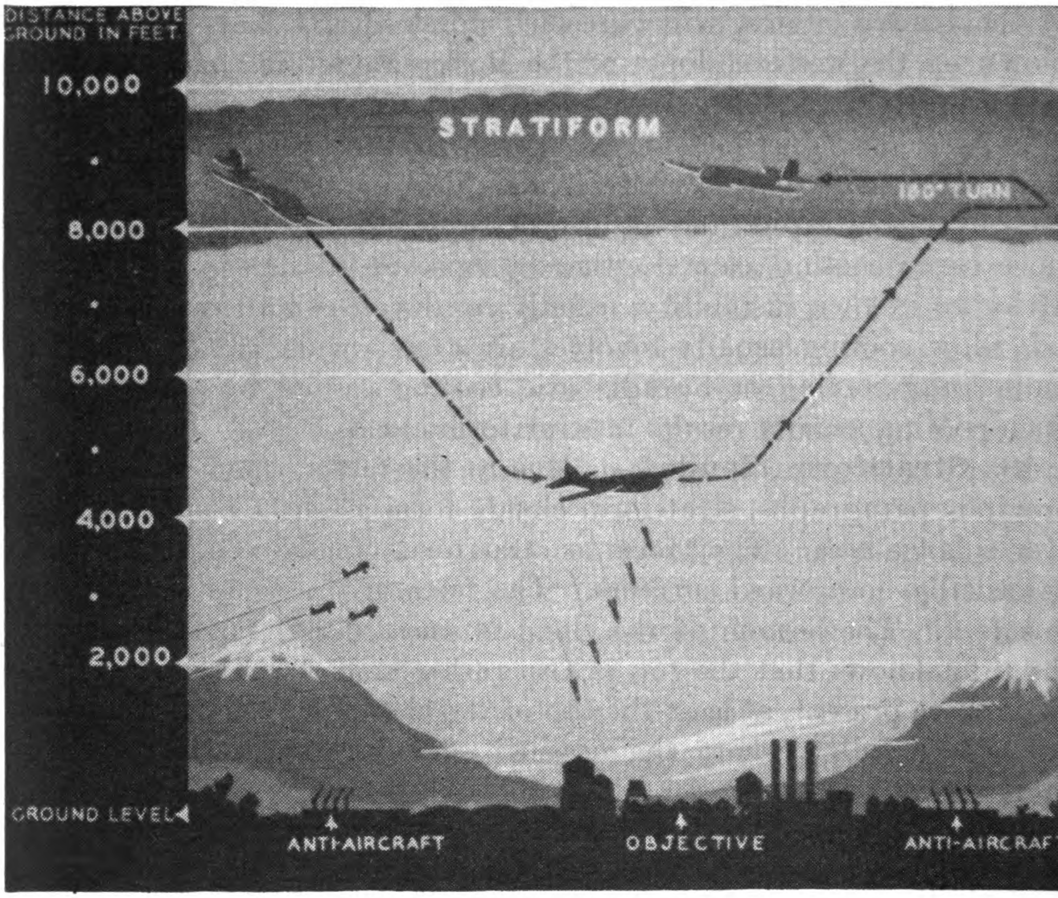


FIGURE 34.—Tactical use of stratiform clouds.

f. A stratiform cloud composed of water droplets at temperatures below freezing offers an icing hazard. The ice thus formed would normally be of the rime type which may be suitably disposed of by deicers. However, an airplane without good deicing equipment should not attempt a prolonged flight in such clouds.

g. The height at which these clouds of different composition will be found depends on such factors as latitude, season, etc. However, an estimate can be made in any particular case. In conditions under which such clouds are found we would except to find the normal drop in temperature of about 2° C. per 1,000 feet. Thus, if the surface temperature were 20° C., it should be safe to fly in a stratiform cloud

at any level below 10,000 feet. A considerably higher level could be used without encountering severe icing conditions. With a surface temperature of 10° C., it would be safe to figure on flying at any level below 5,000 feet, and possibly a thousand feet or so higher.

h. Such estimates, of course, are based on an assumed temperature distribution with height, which may not be precisely correct. The line of reasoning used is sound and will at least give the pilot some idea of what to expect at the different levels. Under such conditions, of course, the free air temperature gage should be frequently consulted. Any time that the temperature drops below zero while flying in a cloud you should expect icing. This is particularly important at night when a considerable load of ice may form before the pilot becomes aware of its presence.

i. If the temperature is known at the level at which you are flying, it is also useful to know how much higher you can figure on going before reaching subfreezing temperatures. The same drop of 2° C. per 1,000 feet should be used in making such estimates. The intensity of precipitation generally gives an indication of the thickness of the cloud and a good indication of the severity of icing that may be expected in case the temperature is below freezing.

NOTE.—Most of the statements above are true only of stratiform clouds, not of cumuliform clouds which are quite different.

49. Cumuliform clouds.—*a.* Stratiform clouds develop horizontally. Cumuliform clouds develop vertically. The presence of vertical current is apparent from the form of the cloud itself. Obviously, all the air over a large area cannot rise at the same time; some must come down. Actually, the air descending must cover a larger area than the air going up so that over a large area cumuliform clouds cannot cover more than half the sky; consequently they are usually reported as scattered, but occasionally they appear to cover more than half the sky and are then reported as broken.

b. Cumuliform clouds have a heaped, or cauliflower, appearance in contrast to the flat appearance of stratiform clouds. The base of each cloud is rather level, and the bases of all clouds will be at about the same altitude. The tops of these clouds will be irregular. This it what would be expected, in view of the fact that the height of the top depends on the intensity of the vertical current which produces the cloud. The vertical currents are characteristic of an unstable condition.

c. The top of the cloud marks the top of the vertical current producing it. The current must be stopped by encountering stable air. Thus, above the top of the clouds we would expect smooth air; in, under, or between the clouds we would expect rough air.

d. The base of cumuliform clouds is usually below 5,000 feet since it is seldom that a degree of stability is attained that would cause dry air to rise higher than that. The top, however, may be at any level, depending only on the degree of instability of the air. Three types, depending on size, are worth considering; namely, cumulus, towering cumulus, and cumulo-nimbus.

(1) *Cumulus.*—(*a*) A cumulus is a small cloud, often seen on summer afternoons. The top of the cloud will usually not be more than 2,000 feet above the base. No precipitation falls from simple cumulus.

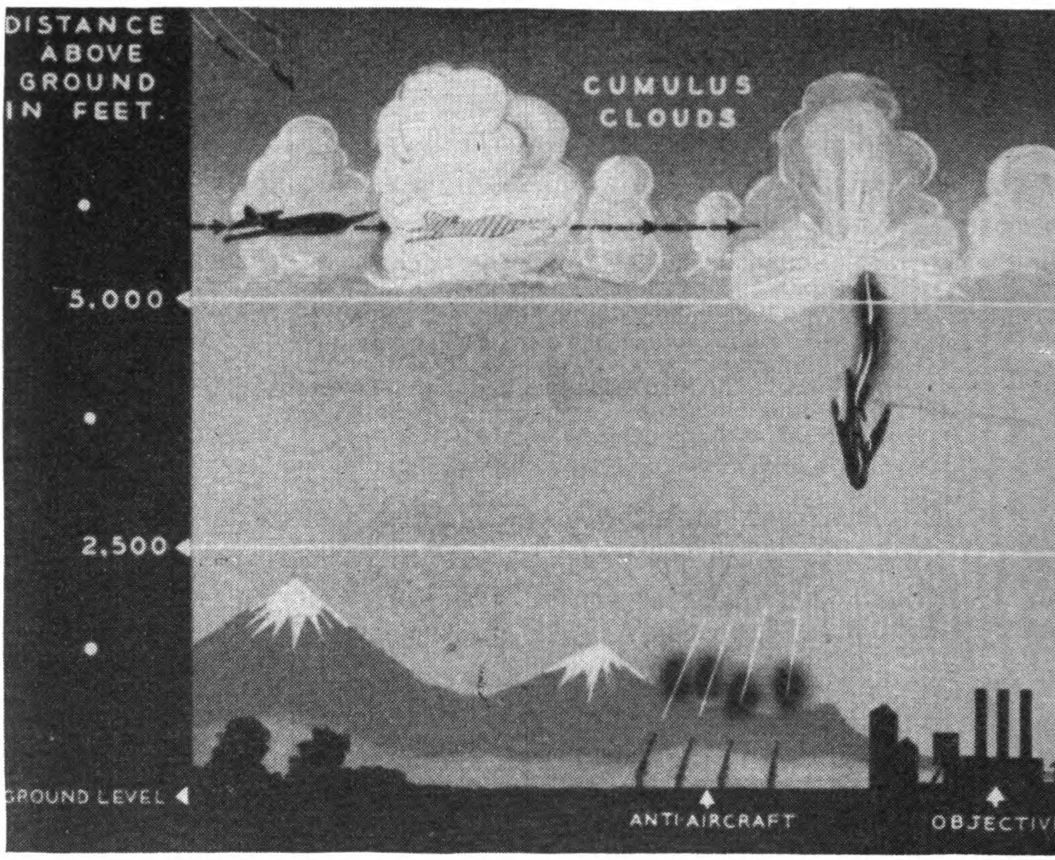


FIGURE 35.—Dangers of cumuliform clouds.

(*b*) The tactical use of cumulus clouds is negative; i. e., it is of value to the enemy. Stories are told by pilots who entered cumulus when the enemy had anti-aircraft artillery in the vicinity. It seems that the enemy had used the cloud as a point on which to adjust his fire, and then arranged matters so that the fire and the airplane would reach the cloud at the same time. What happens under such circumstances has been simply described by the statement, "The cloud explodes."

(2) *Towering cumulus.*—A towering cumulus, or cumulus congestus, is a large cumulus. It may grow from, or degenerate into,

a cumulus. The top may be anywhere from a few thousand to 10,000 or 12,000 feet above its base. Flying in such a cloud is rough, but seldom rough enough to constitute a real hazard. Precipitation usually does not fall from such a cloud. If it does, it will be showery, and may evaporate before reaching the ground. However, a towering cumulus may rapidly develop into a cumulo-nimbus, and a thunderstorm.

(3) *Cumulo-nimbus.*—(*a*) A cumulo-nimbus is a very large cumuliform cloud often covering an area 40 or 50 miles across and extending from low to very high levels, sometimes apparently to the stratosphere. Cumulo-nimbus means thunderstorm with heavy showery precipitation, extreme turbulence, and hail in some part. The top of such a cloud is in the levels at which ice crystals form. When visible, the presence of ice crystals can be recognized by the fuzzy appearance of the top in contrast to the clear outline of the lower part of the cloud. As explained in the section on moisture, the presence of ice crystals can produce rapid development of heavy rain.

(*b*) Such a cloud should be avoided by the pilot whenever possible. Thunderstorms will be covered in more detail in later sections, but at this time it might be stated that the hazard offered by a thunderstorm is probably greater than the hazard offered by enemy gun fire. A flight below the cloud might be successfully negotiated, but it would not be pleasant.

50. Strato-cumuliform clouds.—*a.* Another cloud form is frequently observed which, for lack of a better name, we call strato-cumuliform. Such clouds are cumuliform, but are found in stratified layers with both the tops and bottoms limited.

b. This type of cloud often occurs as a transitional stage with stratiform developing into cumuliform or vice versa. Also, it often happens that a layer of air is unstable with stable air both above and below that layer. Cumuliform type clouds may then develop, but their growth is limited by the stable air above and below.

c. This type of cloud in itself means little to the pilot except as it indicates a change in conditions. For instance, low cumuliform clouds may develop into a stratified layer early in the evening. Such development would indicate the probable formation of a low stratiform cloud deck later during the night.

51. International (type-height) classification.—*a.* The international cloud classification was designed primarily to furnish an international means of classifying clouds. Using this classification, a Frenchman will call the same cloud the same thing that a Norwegian or an American would call it. The classification system is

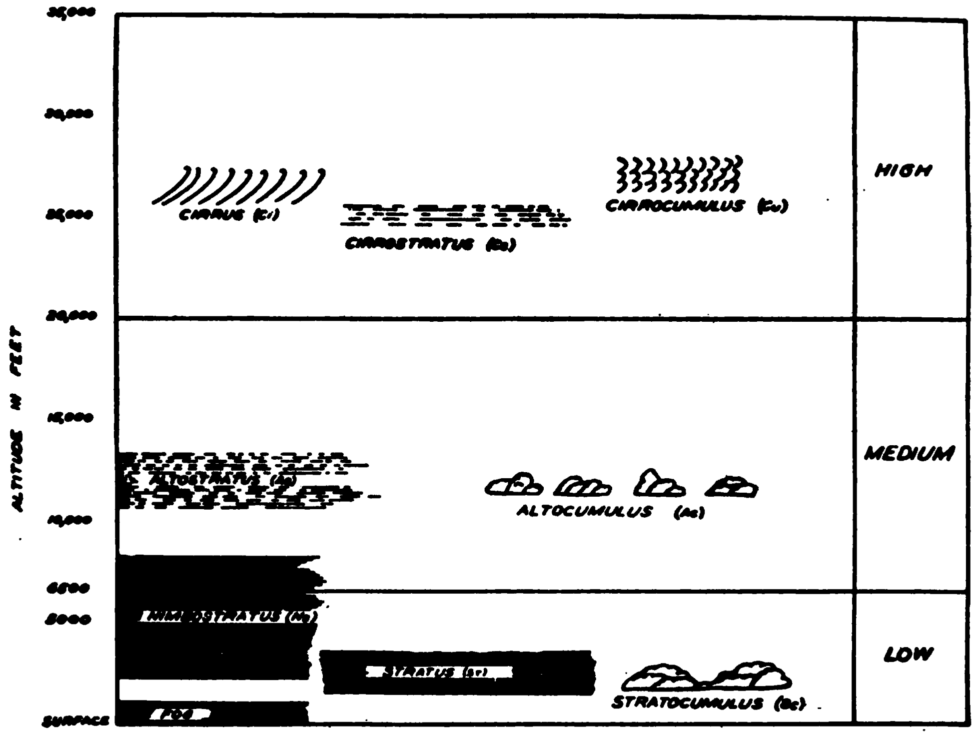


FIGURE 36.—Stratiform and strato-cumuliform clouds.

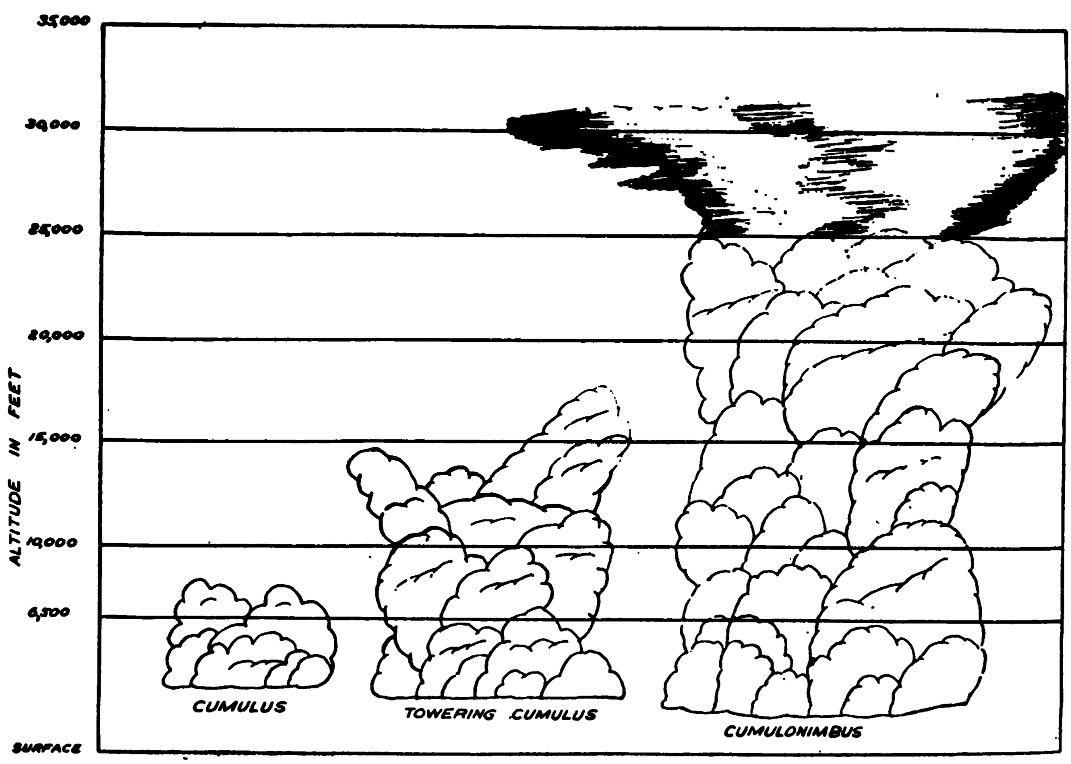


FIGURE 37.—Cumuliform clouds.

very simple for the pilot to remember once he knows what is meant by stratiform, cumuliform, etc. All pilots should at least know the 10 main cloud types since these names are common language among weather men with whom the pilot will talk.

b. Figures 36 and 37 give the name of these clouds and indicate the average altitude of the base. Clouds are classified as high (cirro-), middle (alto-), and low according to the height of the base.

c. A few points in regard to these cloud types are especially worthy of note. Cumulo-nimbus, of course, is associated with thunderstorms. Stratus and nimbostratus often appear the same, but nimbostratus is the common steady rain cloud, and is usually much thicker than plain stratus. Judging only by the height of the base and the appearance of the cloud from below, there might be no difference. However, the precipitation that can come from stratus (usually none) amounts to mist or very fine drizzle. Steady, light to moderate rain means a nimbostratus, which indicates to the pilot that the cloud is thick. The thickness of the cloud tells the pilot how long he will have to fly on instruments during his descent, and, under certain temperature conditions, how much ice he may expect. The presence of larger rain drops in the nimbostratus as well as the greater thickness of the cloud also increases the icing hazard.

QUESTIONS

1. To have a knowledge of clouds is of what value to the pilot?
2. Discuss briefly the classification of clouds with respect to their composition.
3. What is the danger in flying in a cloud composed of supercooled water drops?
4. Give the classification of clouds according to the form they have.
5. Generally, clouds result from the cooling of the air to the dew point temperature. What are the three main ways that this is accomplished?
6. Describe the type of precipitation found associated with stratiform clouds. Why is the precipitation of this type? Explain briefly.
7. Assuming an average air temperature decrease of 2° C. per 1,000 feet, with the surface temperature 50° F., at approximately what altitude may icing occur?
8. Briefly, why are cumulus clouds usually reported as scattered?
9. Are cumulus clouds a good tactical aid? Give reasons for your answer.
10. What is the major hazard associated with cumulo-nimbus clouds?

11. Discuss briefly the type of precipitation associated with cumuliform clouds.

12. Give three reasons why stratiform clouds have operative value in the performance of a mission.

Section VII

HAZARDS

52. General.—*a.* As pointed out in the previous section, some clouds may be used to great advantage by the pilot to effect concealment. Other clouds present hazards which may be greater than the hazards of enemy guns, depending on the relative hazard presented by each. We can say generally that fog, thunderstorms, and icing should be avoided. The pilot is the only one who can judge the hazard presented by the enemy guns. Understanding of the hazard presented by the weather will indicate the action he should take.

b. The major hazards will each be covered in detail in later sections. However, an important part of the discussion of air masses, terrain, and fronts is concerned with the hazards. Thus, the student should know what each hazard is, and what it means to the pilot of an airplane.

c. Also, it will be seen that stability plays the dominent role in connection with hazards as well as with other weather phenomena. Therefore, an explanation of stability is necessary in this section.

d. Fog, thunderstorms, and icing are the most common hazards. Other conditions may be equally serious, or at least annoying, but are much less common. These include any restriction to visibility other than fog, and any extreme turbulence other than thunderstorms. Tornadoes are not mentioned in detail since they are associated with thunderstorms and are rather rare and easily avoided by the man in the airplane.

53. Minor hazards.—*a. Restrictions to visibility.*—Any restriction to visibility which interferes with safe landing or take-off, or with navigation, presents a hazard.

(1) *Dust* may present such a hazard, but dust of such density is rare. A so-called dust storm can occur only under certain special conditions. A strong wind blowing over loose, dry soil may produce dust that is hazardous. If any of these factors are lacking, a dust storm cannot

develop. It cannot develop in a light breeze nor if the soil is damp nor if there is any vegetation on the soil.

(2) *Haze* is very similar to dust except that it results from an unusually high concentration of hygroscopic particles such as sea salt in the air. Haze frequently constitutes an annoyance but seldom restricts visibility to the extent of constituting a hazard.

(3) (*a*) *Smoke* is sometimes extremely annoying and at times presents a hazard. However, smoke is normally associated with industrial areas, and whether or not the smoke will interfere with landing and take-off depends on the wind direction. One side of a city may be clear while the other side has very reduced visibility.

(*b*) *Smoke*, however, is a fine stimulus of fog. A light fog where there is no smoke may become a very dense fog in the presence of smoke.

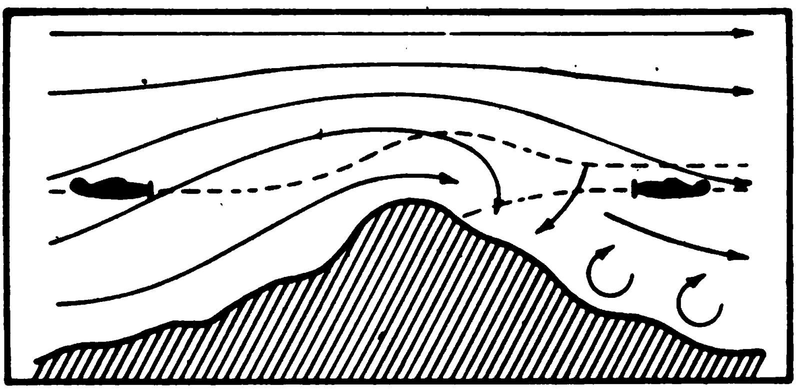


FIGURE 38.—Turbulence over mountains.

b. Turbulence.—Extreme turbulence may be encountered if strong winds are blowing over very rough terrain. The possible effect of a mountain on a strong wind is shown in figure 38. The hazard presented does not concern the pilot who understands the danger and alows a reasonable safety factor.

54. Major hazards.—*a. Fog.*—Fog may be defined as any cloud whose base is on the surface of the earth. Any such cloud restricts visibility. Fog may be so light that it can easily be mistaken for haze, or it may be so heavy that visibility is practically zero. The degree of hazard presented depends not only on the thickness of the fog but also, and of importance, on the type of equipment being operated, and the terrain. Ceiling and visibility that is relatively safe for operations over level ground without obstacles may be very hazardous if associated with rough terrain or any high obstacles. Likewise, restrictions to visibility which would present no serious problems to the pilot of one kind of airplane with good radio equip-

ment might be very serious to the pilot of another type, especially if the radio cannot be used to maximum benefit.

(1) *Formation.*—(*a*) Fog forms like any other cloud when the temperature and dew point come together; that is, when the relative humidity reaches about 100 percent. This state of affairs can come about either by increasing the moisture in the air, or by lowering the temperature to the dew point. Often both occur. Therefore, we would look for formation of fog when we anticipate that the temperature will fall to the dew point, or when there is plenty of moisture to raise the dew point to meet the temperature. Cooling of the air is usually accomplished by one or more of three processes: radiation, advection (flow over a colder surface), and adiabatic (upslope flow). Advection or upslope fog may occur at any time. Radiational cooling, producing radiation fog, can occur only at night or in the early morning. Radiational cooling usually plays some part in the formation of other types of fog so advection or upslope fog is more likely to occur in the early morning.

(*b*) Fog forms most readily in industrial areas where there is a great abundance of highly hygroscopic condensation nuclei. The smoke found in such areas also helps the fog reduce visibility, often to very low and unsafe limits.

(*c*) Low clouds are formed in much the same way as true fog and often result from fog being lifted off the surface. Low clouds also present a similar hazard, the degree of hazard depending largely on the kind of equipment being operated, and the nature of the terrain.

(2) *Persistence of fog.*—(*a*) Condensation can take place near the earth's surface any time the relative humidity approaches 100 percent. Whether or not the cloud so formed will say on the surface and constitute fog depends entirely on the stability of the air. In stable air there is no tendency for vertical currents. Therefore, any cloud that is formed at the surface will remain at the surface as fog. Fog cannot persist in unstable air. Stability can best be understood by considering the distribution of temperature at different levels.

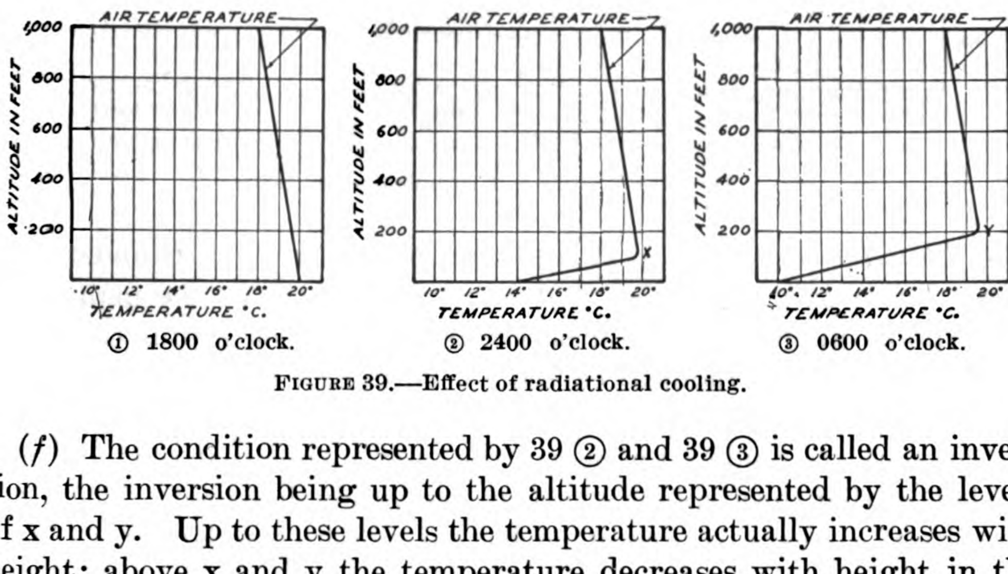
(*b*) Figure 39 ① shows a temperature-height relationship at 1800 o'clock. Between 1800 and midnight no insolation is received, so the earth and the air in the lower levels are cooled by radiation. By midnight the temperature distribution might be as shown in ②; by 0600, as shown in ③. Now let us determine whether or not such air is stable.

(*c*) Referring to figure 39 ②, suppose that air were lifted from the surface to 1,000 feet. The temperature of the air at the surface is 14° C. If lifted, it will be cooled adiabatically. If the air is dry,

it will cool 3° C. for each 1,000 feet, and would then arrive at the 1,000-foot level with a temperature of 11° C. The temperature of the air already at 1,000 feet is about 18° C. Thus, the lifted air would be colder and heavier and would tend to sink back to the surface.

(*d*) Similarly, suppose the air existing at 1,000 feet were moved to the surface. It would be heated adiabatically, would arrive at the surface warmer than the air already there, and would thus be lighter and tend to rise back to the 1,000-foot level.

(*e*) This has assumed that the air were dry. In case of fog formation, of course, the air would be wet; thus the air would cool upon being lifted at the wet adiabatic rate. The reasoning involved is exactly the same except that the rate of cooling will be obtained from an adiabatic chart and will be found to be about 1½° C. per 1,000 feet.



① 1800 o'clock. ② 2400 o'clock. ③ 0600 o'clock.

FIGURE 39.—Effect of radiational cooling.

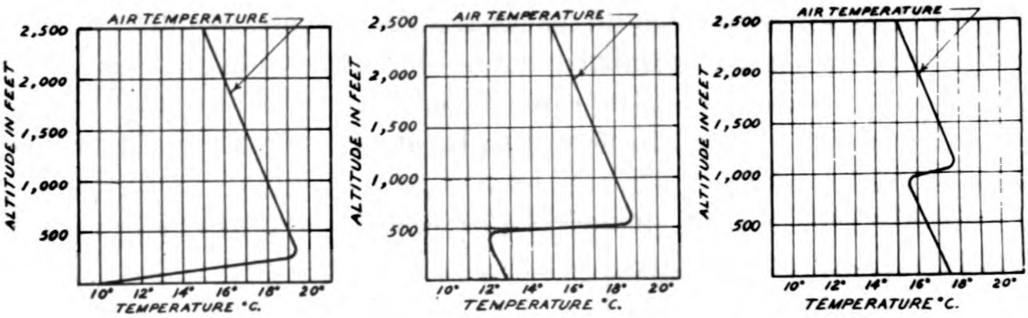
(*f*) The condition represented by 39 ② and 39 ③ is called an inversion, the inversion being up to the altitude represented by the levels of x and y. Up to these levels the temperature actually increases with height; above x and y the temperature decreases with height in the normal manner.

(*g*) An inversion indicates a condition that is very stable for both wet or dry air. There can be no tendency for vertical air currents. Thus, a cloud formed at the surface would remain at the surface until dissipated by heat or stronger wind.

(*h*) Wind also plays an important role in the formation and persistence of fog. A light wind aids formation, while a strong wind renders the air in the lower layers unstable, and will cause low clouds rather than fog. Wind, of course, causes turbulence, and turbulent mixing of the air in the levels affected. The stronger the wind, the deeper the layer of air that is mixed. The temperature distribution will then become somewhat as shown in figure 40.

(*i*) Under conditions as represented by ①, where no mixing will occur, a layer of fog would be only a few feet deep. A light wind as

represented by ② would produce some turbulence. The inversion would be lifted off the ground as a result of mixing. The top of the cloud would be limited by the inversion. In this case the cloud would in all probability reach the ground as fog. A stronger wind as represented by ③ would mix a deeper layer of air and lift the inversion still higher. In this case, therefore, we would expect low stratus with little probability of the cloud reaching the ground. However, such a low cloud may constitute nearly as great a hazard as fog.



① Calm. ② Wind 7 mph. ③ Wind 20 mph.

FIGURE 40.—Effect of turbulent mixing.

b. Thunderstorms.—(1) To the man on the ground, thunderstorm means heavy rain, lightning, and sometimes hail. To the man flying an airplane in the storm it means extreme turbulence plus the possibility of structural damage caused by large hail stones. The turbulence may be so violent that the airplane cannot be controlled, that gyro instruments are rendered useless at the precise time that they are most needed, or that the airplane structure is severely damaged. The lightning itself appears to present no hazard worth considering.

(2) Many stories of flying in thunderstorms have been told and put on record. These include such matters as a thermos jug leaving a transport plane through a hole it made in the top; half the wing bolts being sheared off; and various hatch covers, cowling, and other more essential parts of the airplane being carried away. Many pilots have been in a thunderstorm once, but not many twice. At least, there are very few pilots who intentionally go into a thunderstorm more than once.

(3) Apparently, a tornado condition can exist in any thunderstorm. Encountering a tornado in the cloud seems to be the only reasonable explanation for damage that has occasionally been reported. This does not mean that every airplane that flies in a thunderstorm will run into a tornado, but it is possible, and extreme turbulence is certain in any event.

(4) The form of a thundercloud itself shows the presence of strong vertical currents. The existence of hail, and the heavy showery rain further proves the existence of strong vertical currents; and in addition, that strong up-currents may be found in close proximity to down-currents. The extreme turbulence experienced results from encountering the various different air currents.

(5) The presence of vertical currents requires that the air be unstable. Thunderstorms can neither develop nor persist in stable air.

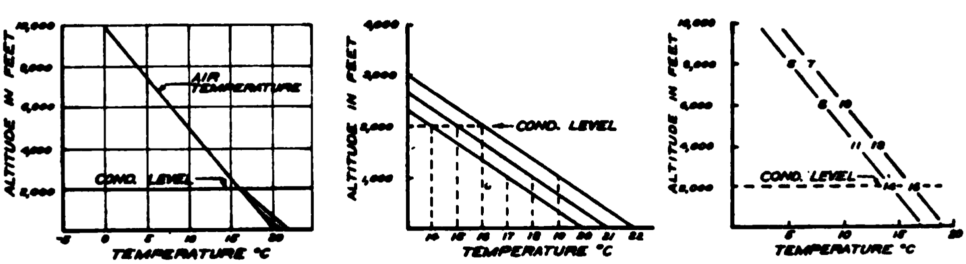
FIGURE 41.—Some fun?

(6) In figure 39 a stable condition was shown. Now refer to figure 42 and apply the same line of reasoning. Figure 42 ① shows the air temperature curve with the surface temperature increasing from 20° to 21° and 22° C. by the sun's heating. Figure 42 ② shows the rate of cooling for dry air as it rises, or, the rate of heating as it descends; in either case 3° C. per 1,000 feet. Figure 42 ③ shows the rate of cooling or heating for saturated air as it rises or descends; in either case about 1½° C. per 1,000 feet.

(7) From figure 42 ②, one notes that air at the surface with a temperature of 20° C. will cool dry adiabatically (3° C. per 1,000 feet), if lifted, and arrive at 2,000 feet with a temperature of 14° C. As seen from figure 42 ① the air at 2,000 feet has a temperature of 16° C. Thus, the lifted air would be 2° C. colder than the surrounding air and would tend to return to the surface. This is a stable condition.

(8) However, suppose the surface were heated by insolation as indicated in figure 42 ①. The temperature of the air near the surface would rise. First consider the state of affairs when the tem-

perature of the air at the surface becomes 21° C. From figure 42 ②, you can see that surface air with a temperature of 21° C. will arrive at 1,000 feet 3° cooler, having a temperature of 18° C. This is the same temperature as that of the air already at 1,000 feet as indicated in figure 42 ①. There would then be no tendency for the air to return to the surface; that is, air with such a temperature distribution would not resist lifting to the 1,000 foot level. If the same air were lifted further, it would arrive at the higher levels with a temperature lower than that of the air already at those levels, and would, therefore, tend to return to the 1,000 foot level. For example, as indicated by figure 42 ② the lifted air would have a temperature of 15° C. at 2,000 feet, whereas, as shown by figure 42 ①, the air at 2,000 feet has a temperature of 16° C. Being colder, and thus heavier, than the surrounding air at 2,000 feet, the lifted air would tend to return to 1,000 feet. It would resist lifting above the 1,000 foot level.



① Air temperature. ② Dry adiabats. ③ Wet adiabats.

FIGURE 42.—Effect of diurnal heating.

(9) Now consider what happens when the surface temperature reaches 22° C. As indicated in figure 42 ② surface air of temperature 22° C. would, if lifted, reach the 2,000-foot level at 16° C., the same temperature as the air already at 2,000 feet as indicated by the air temperature curve of figure 42 ①. The surface air, therefore, would not resist lifting to 2,000 feet. Further heating at the surface would produce a tendency for the air to rise above the 2,000-foot level. Such air would then be unstable to higher levels.

(10) Here the condensation level is given as 2,000 feet. In other words, surface air lifted to that level will be cooled to saturation. Condensation and the beginning of the formation of a cloud, with its base at 2,000 feet, will result. Further rise of the air will then be accompanied by cooling at the wet adiabatic rate, about 1½° C. per 1,000 feet. It will then be seen, by figure 42 ③, that wet air at 2,000 feet at 16° C. will not resist further lifting. At 4,000 feet it would actually be warmer than the air already at that level (13° C. as compared to 12° C.), and would, therefore, continue to rise. More water

vapor will condense as the air continues to rise and cool. The small cumulus cloud formed at 2,000 feet will develop vertically.

(11) In the discussion of fog it was shown how cooling at night increases stability near the surface. Here it is shown how heating during the day decreases stability, or produces instability.

(12) A temperature distribution such as indicated in figure 42 ① represents conditions under which thunderstorms might be expected during the day, that is, most probably in the late afternoon and in summer.

(13) The condition discussed above is one way by which instability may develop and possibly produce thunderstorms. This is not the only way that thunderstorms may develop, but in any event a thunderstorm requires that the air be unstable.

(14) For example, consider what would happen if the air previously discussed were blown up a slope. The up-slope effect is extremely important in regard to weather in the western part of North America and in the mountainous regions in the eastern part.

(15) Again refer to figure 42. Suppose the wind were to force the air up a slope. As indicated by ②, air starting at sea level at 20° C. will reach the 2,000-foot level with a temperature of 14° C. It will be colder than air already at that level, which is 16° C. as indicated by ①. This air, now saturated and having a temperature of 14° C. at the 2,000-foot level, will cool at the wet adiabatic lapse rate (about 1½° C. per 1,000 feet) as indicated by ③. This rising air will continue to be colder than the surrounding air until the 6,000-foot level is reached. Here, the temperature of the rising air (as indicated by ③) is 8° C., the same as the temperature of the air at 6,000 feet (as indicated by ①). Above that level it will be warmer than the air at those levels and would, therefore, tend to continue to rise of its own accord. For example, at 8,000 feet the rising air will have a temperature of 5° C. (as indicated by ③), whereas the air at that level will have a temperature of about 4° C. (as indicated by ①). This level (6,000 feet in this case) is known as the level of free convection. The air is stable below this level. But if it is forced to the level of free convection, it becomes unstable and will continue to rise.

(16) This is the condition that produces frequent thunderstorms on the windward side of mountains.

c. Icing of aircraft.—Regardless of modern deicing equipment, aircraft icing still presents a major hazard. Actually, icing is rather rare; however, when encountered, it may be very serious. The problem is aggravated by the fact that, when icing is encountered, the weather is not as forecast. Otherwise, the icing area would have been avoided.

Thus, it is up to the pilot to decide what to do about it; there is little information on which the pilot can base his decision.

(1) *Theory of ice formation.*—Ice may form on the airplane any time there is liquid water present at subfreezing temperatures. As pointed out in the section on clouds, liquid water frequently exists at below freezing temperatures, both as cloud particles and as rain. In either case the liquid is in an unnatural state at such temperatures. This supercooled water, when agitated by striking the airplane, will freeze and icing will result.

(2) *Types of ice.*—(*a*) Two main types of ice form on aircraft, clear and rime. Clear ice is compact, the kind of ice that forms in a so-called sleet storm; the kind that sometimes forms on the windshield of an automobile; the kind you buy from an ice man. Rime is porous, more like snow that has been frozen into one mass.

(*b*) Clear ice is strong and tenacious, and often builds up very fast. Rime is weak, usually builds up more slowly, and can be handled satisfactorily by deicing equipment. Clear ice sometimes cannot.

(*c*) Most ice actually formed on airplanes is a combination of clear and rime, with one type predominating. The pilot often has trouble in deciding which is the predominant type. However, the form in which the ice forms over the airfoil rather than the type of ice is of primary interest to the pilot who is flying in icing conditions. Rime ice usually builds up rather evenly, and does not destroy the airfoil characteristics. Clear ice forms in a sort of mushroom shape on the leading edges of airfoils and in a short time may completely destroy the aerodynamic characteristics of the airfoil.

(3) *Favorable conditions for rime and clear ice.*—(*a*) Rime generally forms when the water droplets are small and when the temperature is low. Clear ice forms when the water drops are large and when the temperature is not much below freezing; generally, clear ice will not form at temperatures below −8° C. although rime may form at temperatures as low as −30° C. or lower.

(*b*) Small droplets are associated with stable air. Large drops are associated with unstable air. Consequently, we would expect that ice encountered in stable air would be rime, and ice encountered in unstable air would more often be clear. The correctness of this assumption is borne out by experience. Generally, smooth air means rime ice, if any, and not a very serious hazard. Rough air means clear ice, if any, and a much greater hazard.

55. Summary.—*a.* It has been pointed out that the major hazards to aviation are all directly associated with stability or instability in the atmosphere. Fog can form and persist only in stable air. Thun-

derstorms can form and persist only in unstable air. Clear ice, the most dangerous kind, appears to form only when associated with unstable air. Rime ice, the less dangerous kind, forms in stable air.

b. The pilot should bear in mind that the hazardous conditions only constitute real hazards when he encounters them unexpectedly and does not know what to do about it. Most of his troubles can be avoided if he clearly understands the general weather situation that prevails during each flight, *and* if he clearly understands the factors whose change may determine the existence or nonexistence of a

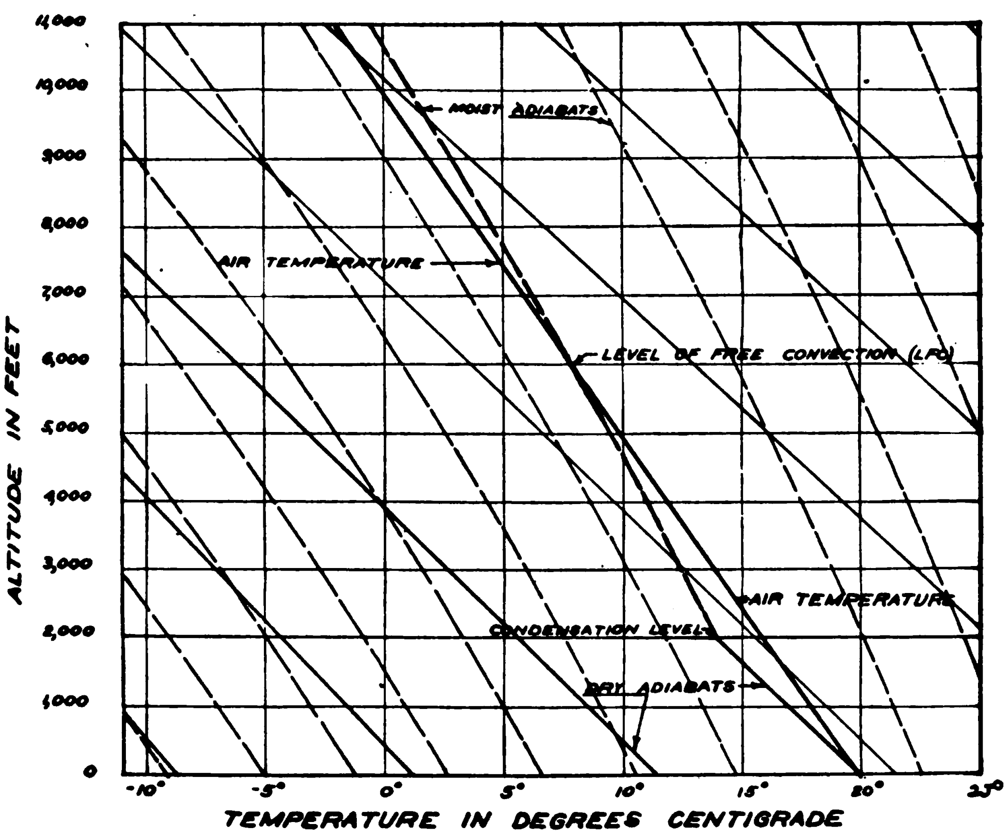


FIGURE 43.—Adiabatic chart.

weather hazard. The controlling factor is usually stability of the air. Stability in the atmosphere depends upon the temperature and temperature does not remain constant. Thus, the major problem is for the pilot to know what temperature changes are likely, and what such changes will do to stability.

c. The simplest way to show air temperatures is by means of a graphic representation which itself gives a picture of stability conditions. In the presentation in this section air temperature, dry adiabats, and wet adiabats were drawn on different charts. Actually, the air temperature is drawn on an adiabatic chart which shows dry and

wet adiabats. Figure 43 shows an adiabatic chart solving the air temperature problem of paragraph 13 concerning thunderstorms.

d. These major hazards will be covered in more detail in the following sections on air masses and fronts, and again summarized in separate sections dealing with each of these hazards.

QUESTIONS

1. Of what value is an understanding of the hazards presented by the weather?
2. Give the three major hazards.
3. In general, what do we mean when we speak of hazards?
4. In studying hazards, of what aid is a knowledge of clouds?
5. Give three methods by which fog might be formed.
6. Define stable air. Unstable air.
7. Does an inversion represent an unstable or stable state?
8. Briefly, what is the relationship between stability and fog?
9. What role does wind play in fog formation and persistence?
10. Briefly, why are thunderstorms a major hazard to the pilot?
11. At what time of day do thunderstorms usually occur? Why?
12. Name the two main types of icing. Which is the more dangerous and why?
13. How does stability govern the type of hazard?
14. What weather preparations should a pilot make before taking off?

SECTION VIII

INTRODUCTION TO AIR MASSES AND FRONTS

56. General.—*a.* All weather is associated with either one particular air mass or with two or more air masses, in which case the different air masses are separated by a so-called front (see fig. 44).

b. A weather front has been compared to the front of an army—it is where most of the action takes place. However, there is also a great deal of activity behind the front, usually of a less violent nature. Continuing the same analogy, much more area is affected by the air mass away from the front than by the front itself.

57. Air mass.—*a.* An air mass may be defined as a large body of air with uniform characteristics over a large area, usually an area

some thousands of miles across. Flying at any level, it would be found that temperature and moisture content of the air would change very slowly and consistently. There would be no sudden changes. Likewise, except for local causes, the weather will remain the same over large areas.

b. Thus, if a graph is plotted using the temperature of stations along the line *AA* of figure 44 against the horizontal distance between Fargo, North Dakota, and Brownsville, Texas, figure 45 is obtained which shows very clearly the gradual uniform change of temperature within

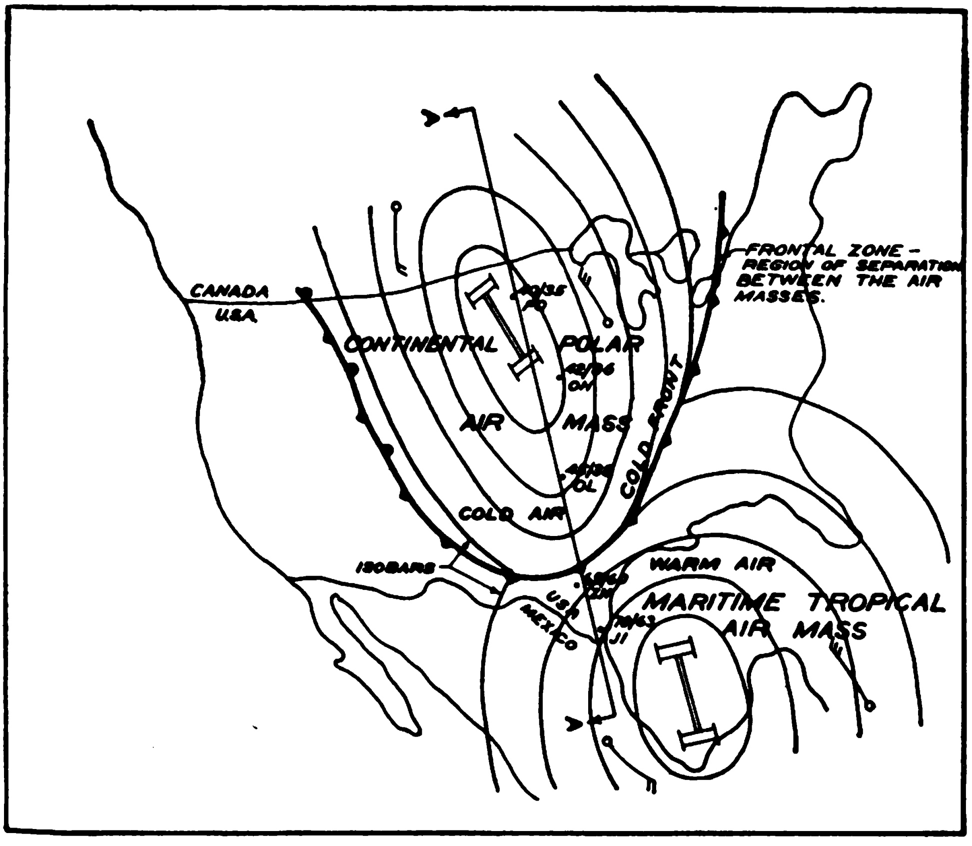


FIGURE 44.—Section of weather map showing two distinct air masses separated by a front.

the air mass, and a marked discontinuity occurring at the separation of these air masses. A similar graph could be shown for specific humidity.

58. Source regions.—*a.* As mentioned in previous sections, there are large areas of the earth's surface with very different characteristics. There are cold and warm, wet and dry. Furthermore, there are certain large areas, such as Siberia and the North Pacific, in which surface characteristics are uniform and change only very slowly between widely separated points. Air which remains over such a uniform surface for a long enough time will acquire the characteristics

of the surface, cold or warm, wet or dry. In order for the air to remain over the surface long enough to become an air mass, a high pressure area must exist over that surface. Air masses cannot be formed in areas of low pressure; rather it is in the low pressure that different air masses are brought together, resulting in a front.

b. Reference to figure 46 shows the existence of prevailing high pressure systems over such uniform surfaces in winter and in summer. It is in such areas that air masses are formed. They are called source regions, the region in which the air mass acquires its characteristics, and the source from which such air comes.

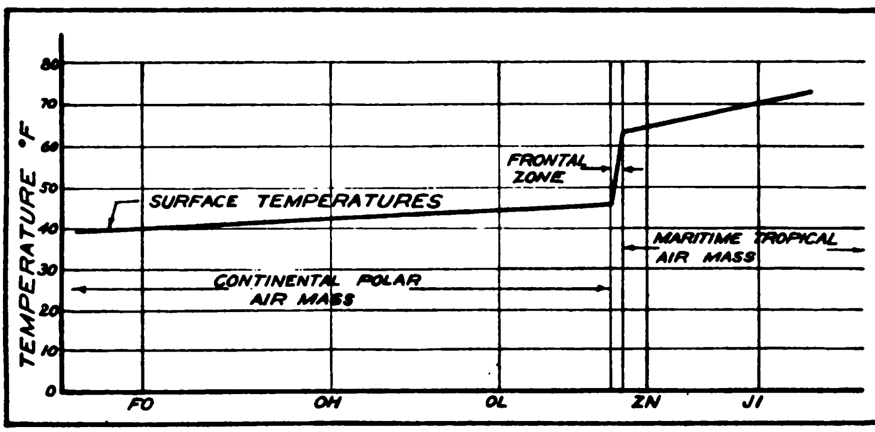


FIGURE 45.—Gradual uniform change of temperature within an air mass.

59. Designation of air masses.—*a.* Further inspection of figure 46 will show that source regions generally lie either in tropical or in polar regions. Air masses may be formed in equatorial or arctic regions as well, but these are similar to the tropical and polar air masses and seldom concern us. The air mass is designated on the map by a large blue P for polar (blue A for arctic), and red T for tropical (red E for equatorial). We are concerned primarily with the P and T types.

b. Also, the source region may be wet and dry, that is, maritime or continental. Thus, we find mP air, meaning maritime polar; cP, meaning continental polar, etc.

c. These designations tell us what the air is or was in its source region.

d. We are also vitally interested in another factor when the air moves out of its source region. As has already been pointed out, weather depends largely on the degree of stability of the air. The degree of stability in turn depends very largely on whether the air is being heated or cooled near the surface. Thus, it is important for us to know whether the air is flowing over a warmer or colder

surface. This information is given by designating thus: mPw, meaning maritime polar air that is warmer than the surface over which it is moving. The first, mPw, for example, might be air from the North Pacific in winter flowing over Canada; mPk might be the same kind of air flowing over the warmer Pacific farther south.

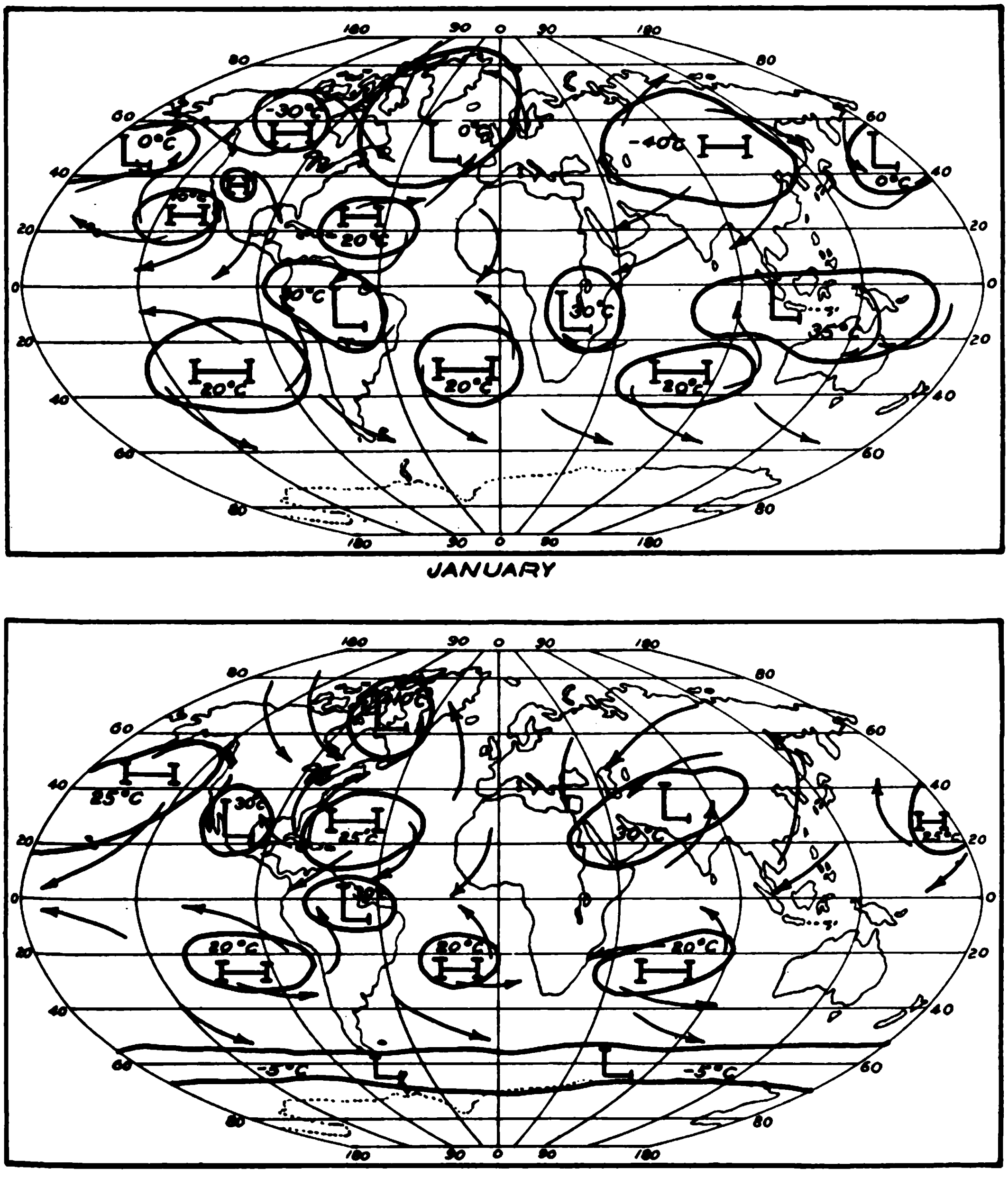


FIGURE 46.—Prevailing high pressure systems which act as source regions.

e. These terms will not be confused if it is remembered that when we speak of warm air, we mean air that is warmer than the surface. A cold wave is spoken of when cold air flows over the surface.

f. It is important that the student get these designations clearly fixed in his mind at this time since, for the sake of convenience, they will be used throughout the remainder of this manual.

60. Front.—*a.* It is common knowledge that fluids of different density, such as oil and water, do not readily mix. Similarly, two types of air with different densities do not readily mix. When two such types, as cPk and mTw, come together, a front is formed. The colder, heavier air pushes under the warmer, lighter air.

b. We might call the surface of the ocean, or of a river, a front. In that sense the front would be the surface that separated the heavy water from the lighter air. The front would not be a fixed surface; there are waves, and the river might rise, but the front would mark the place where the water stopped and the air started. Wherever the water goes, whether into Lake Michigan or the Atlantic Ocean, the front is still there, telling where the water stops and the air starts.

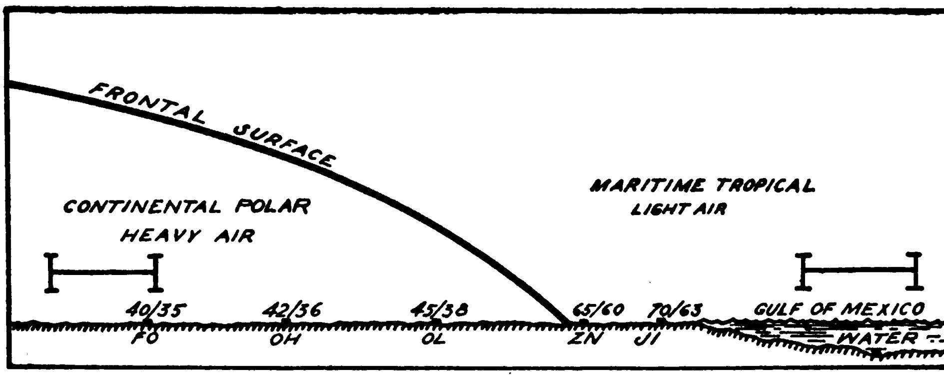


FIGURE 47.—Vertical cross section along *AA* of figure 44.

c. Similarly, we may visualize a front in weather as marking the place where the heavy air stops and the lighter air starts. It is *the surface of the heavier air*. It is not a fixed surface, but moves with the heavier air.

d. This can be more easily explained by use of the following diagram. If we draw a vertical cross section through figure 44, intersecting the ground in a line through the points of Fargo, Omaha, Oklahoma City, San Antonio, and Brownsville, Texas, we obtain the vertical cross section as shown in figure 47.

e. Fronts, and weather associated with fronts, will be covered in more detail in later sections. At this time it is only necessary for the student to understand what a front is; also to know that when a front exists, it is the main factor controlling the weather.

QUESTIONS

1. Define air mass, source region, and front.
2. What do we mean when we speak of air mass weather? Frontal weather?
3. How are air masses designated geographically? With respect to the surface over which they are formed?
4. Air masses are referred to as either cold or warm, the difference being a relative characteristic. Explain briefly.
5. As an air mass moves away from its source region, how is its stability affected?
6. Is frontal weather of any great concern to the pilot? Why?

Section IX

AIR MASS WEATHER

61. General.—*a.* As long as we are dealing with only one air mass, weather is controlled primarily by moisture content of the air, relation of surface temperature and air temperature (stability), and relation between wind and terrain (up or down slope). A pilot should have a clear idea of the effect of each of these factors. Also, he should understand the relation between them so that he will know which factor will play the dominant part in case two are in conflict.

b. Most of these factors have been covered rather briefly in previous sections. We know that rising air is cooled. Conversely, descending air is warmed. Condensation takes place when the air is cooled approximately to its dew point. Conversely, a cloud warmed above the dew point temperature will evaporate and dissipate. We also know that stability tends to increase if the surface temperature

is reduced. Likewise, it tends to be increased if the temperature of the air at higher levels is increased while the surface temperature remains the same. Conversely, stability tends to be reduced if the surface temperature is increased, or if the surface temperature remains unchanged and temperatures aloft are reduced.

c. We also know that smooth, stratiform clouds are associated with stable air. Bumpy, cumuliform clouds are associated with unstable air. Fog is associated with stable air, whereas thunderstorms and the most hazardous icing are associated with unstable air.

d. The pilot should know how these factors affect the weather in which he may be flying. Since no one knows where the student will be flying 6 months after studying this manual, there is no use placing special emphasis on local conditions except to point out the application of principles. The important thing is learning how to apply the principles logically. Since weather data is most readily available for North America, the examples given deal mostly with North America.

e. Also, most emphasis is placed on winter conditions since they are most clearly defined. The same principles apply any time, but summer conditions are usually much milder and present much less hazard to aviation.

62. Maritime polar air (mP) in source region.—Consider the characteristics of air that has been over a cold maritime region in winter for a considerable length of time—such a region as the North Pacific. So long as the water is not frozen, the surface temperature will be somewhere around 0° C. (32° F.). From the section on moisture, it is known that air at this temperature will not hold very much water vapor although it may be nearly saturated. Such air would probably have close to the average decrease of 2° C. per 1,000 feet—a stable condition unless the air is subject to considerable forced lift.

63. Maritime polar air (mP) entering west coast.—*a.* Such polar maritime air often moves southward over the warmer waters of the Pacific and across the western coast of Canada and the United States.

b. As long as the air mass is passing over the warmer ocean surface it will be moving as mPk. The air near the surface will be heated which will make the air in the lower layers less stable. Also, water vapor will be added to the air due to evaporation from the relatively warm water surface.

c. Due to the decreased stability of this air, little or no resistance is offered to its passage over the coast ranges and the higher Sierra Nevada, Cascade and Rocky Mountains. Considerable precipitation

results in these areas as the air loses much of its moisture content due to this lift.

d. The effect of the terrain is shown in figure 48. Flying conditions in such air will be good, except in the areas where this air is lifted. Here cumuliform clouds will form, resulting in showers and snow squalls in mountainous regions. Along mountain ranges, turbulence will be considerable due to the instability of the air plus the high velocities associated with the movements over the irregular terrain. Icing condition over the mountains may be severe, and of the clear ice type. However, keep in mind that these hazardous conditions will be localized, existing only in places where lift is occurring.

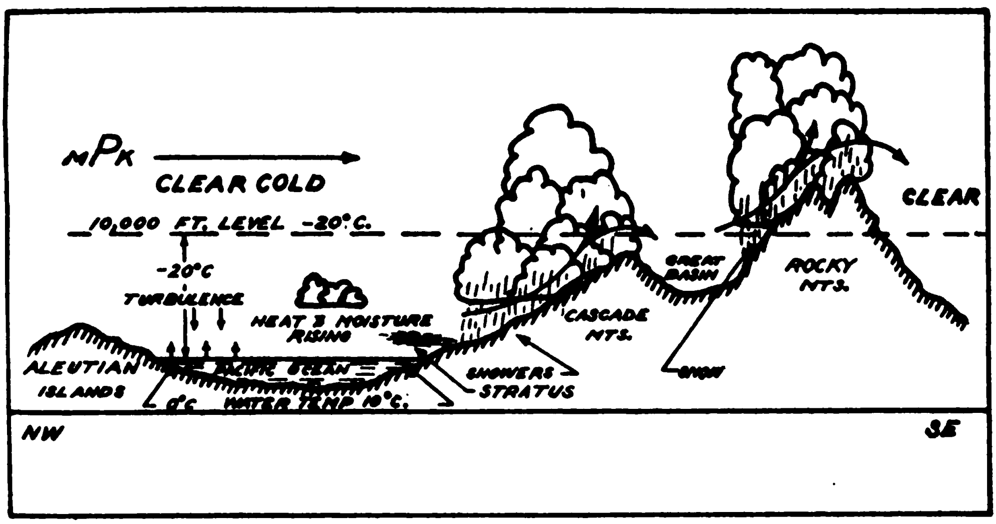


FIGURE 48.—Movement of mPk air southeastward.

e. Since the air would be heated adiabatically as it descended on the eastern slope of these mountains, the clouds will be completely dissipated on the leeward side. The effect of this adiabatic heating is shown in figure 49.

64. Transition to continental polar (mP to cP).—*a.* Suppose now that this mP air from its source region (temperature 0° C.) moves over the cold ice-covered region north of Alaska in winter. It will not be subject to appreciable lift, so we will temporarily disregard the lift effect.

b. The air will now be moving over a surface which has a temperature in the neighborhood of −40° C. Therefore, it will be moving as mPw. The air near the surface then will be cooled very rapidly. This will result in pronounced stability in the lower layers, which will extend to higher levels as time goes on. Also, with such cooling, condensation might be expected, and with the extreme stability, any con-

densation would result in fog. In the far north there is very little heating effect from the sun in winter, and the winds would usually be light. Thus, fog, if formed, might exist for days or weeks. A stronger

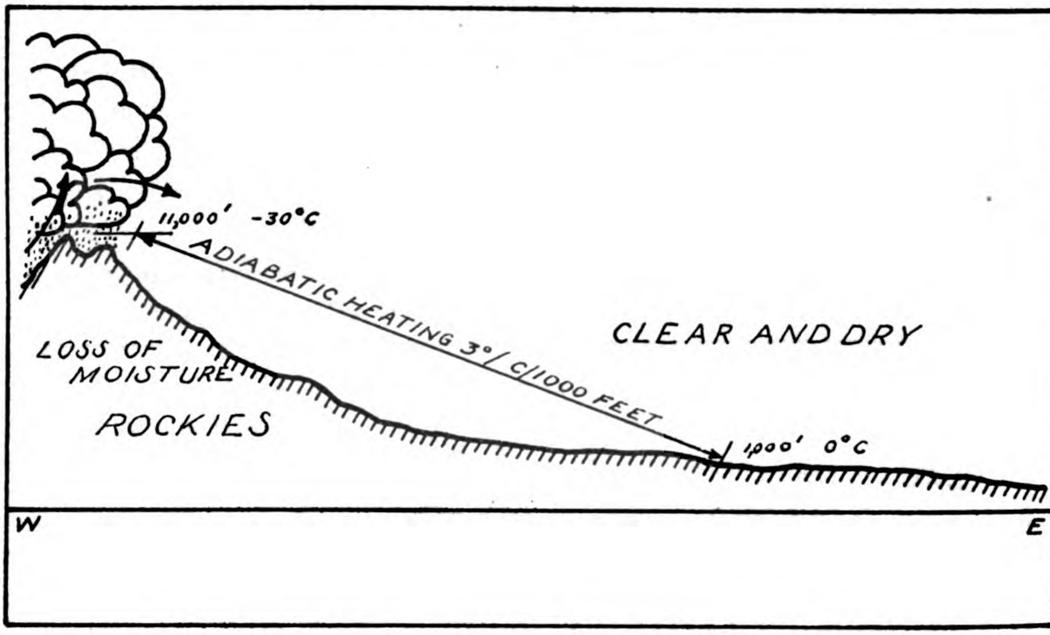


FIGURE 49.—Effect of adiabatic heating.

wind might render the lower layer of air unstable and lift the fog to form low stratus, which might be just as serious to the pilot as fog. These phenomena are indicated in figure 50.

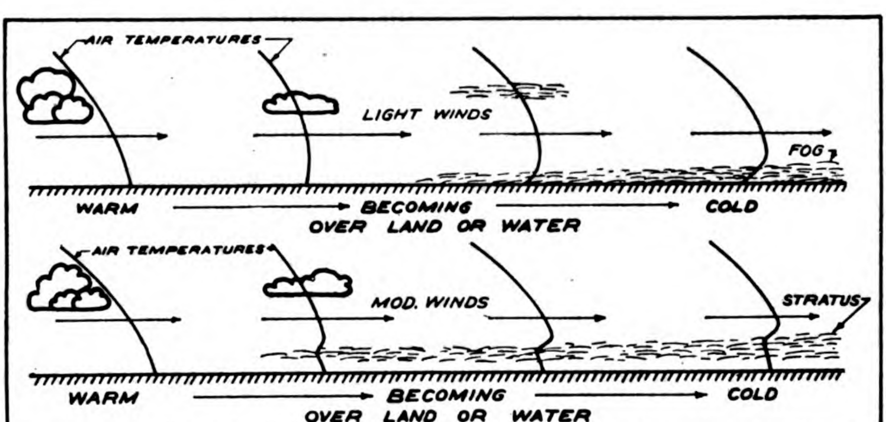


FIGURE 50.—Passage of warm air over colder surface.

c. As time goes on the cooling will affect a deepening layer of air, extending the stability to higher levels. This is indicated in the section on temperature by figure 8. Above this very stable layer, however, the air would be very clear and cloudless.

d. Thus, cP in its source is characterized by pronounced stability with poor visibility in the lower levels and very good visibility above. Figure 51 ① shows the result of plotting temperature against elevation for a winter sounding of polar continental air in its source region. Figure 51 ② gives a pictorial representation of the weather associated with the cP air mass.

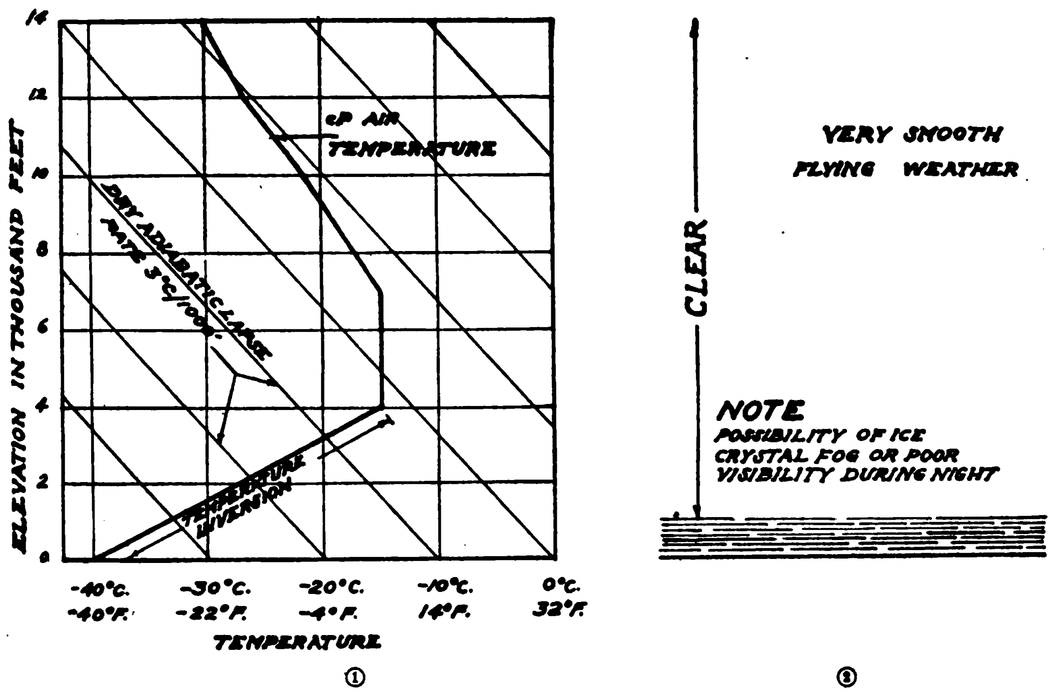


FIGURE 51.—Polar continental air in source region.

e. Even though the formation of fog appears likely under such conditions, in the cP source region as a whole flying conditions are very good.

65. cPk air.—*a. Warmer land trajectory.*—(1) Above we talked about cP in its source region. Now, we will consider what happens as this air moves out of its source as a cold air mass moving over warmer land.

(2) The air moving southward will be flowing over a surface that is gradually becoming warmer. Thus, the lower layers of the air will gradually be heated and the marked degree of stability will decrease. So long as the air is moving over a snow-covered surface (temperature 0° C. or less), the decrease in stability will not completely eliminate the stable effect previously acquired in the higher levels at the source region. Usually, an outbreak of polar air is accompanied by a fairly strong wind, 20 mph or more. This wind will assist in decreasing the stability in the lower levels. This decrease in stability is shown in figure 52.

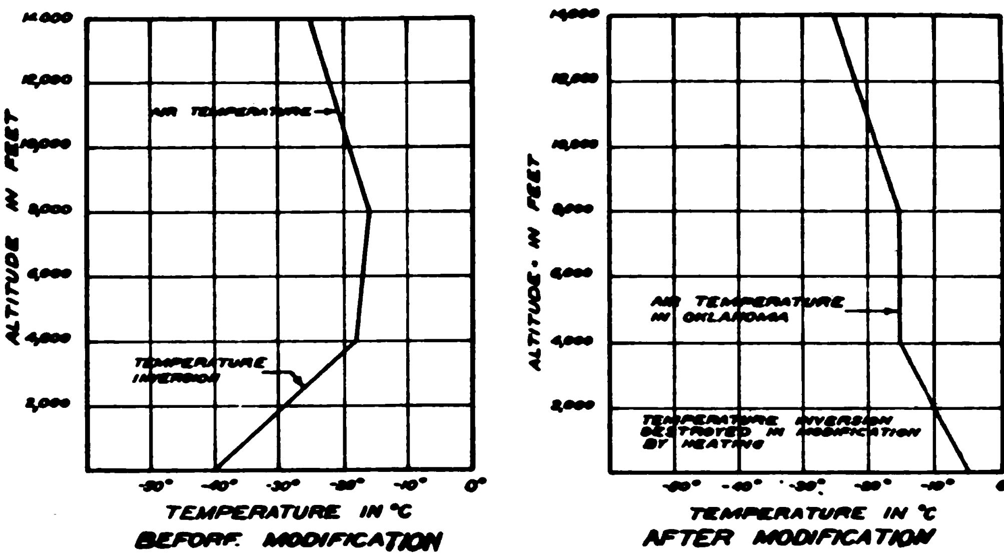


FIGURE 52.

(3) Thus, if this modified air moves very rapidly over rough country, the turbulence will produce low strato-cumulus clouds with occasional light snow flurries as shown in figure 53.

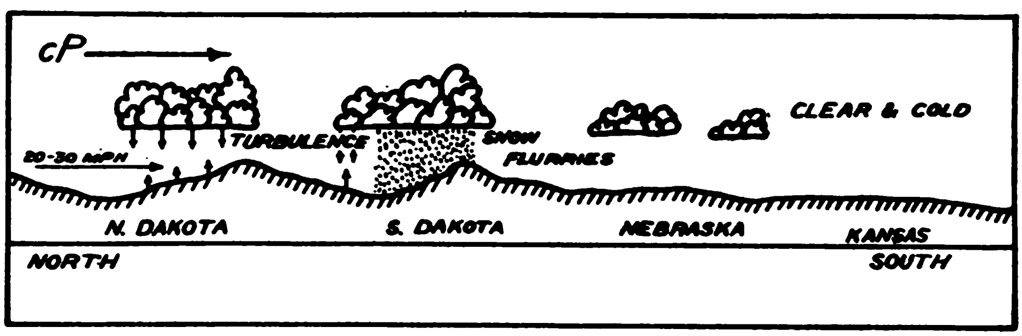


FIGURE 53.—cP air moving southward.

(4) After the air has passed the snow cover and moved over a surface with temperature above freezing, we would normally find rapid changes in air properties. The surface temperature would increase very rapidly, and soon eliminate the former stability that previously existed. However, since the heating from below is more rapid than the addition of moisture, the relative humidity is decreased. Consequently, clouds are not to be expected because of the tremendous convective lift necessary to produce saturation. Cumuliform clouds will form whenever the supply of moisture is sufficient to lower the condensation level, as when cPk air moves over the Great Lakes.

(5) Except for the clouds and associated weather over rough terrain, visibility and other flying weather should be very fine.

b. Interrupted flow, over water.—(1) A particularly troublesome situation often arises if the cold air flows from a cold, snow-covered surface over open water and then over a cold, snow-covered surface again. This frequently happens with air flowing over the Great Lakes, and the resulting weather has accounted for a great many accidents in the mountainous area east and southeast of the Great Lakes.

(2) Air flowing over such open water will experience rapid heating near the surface, resulting in rapidly developing instability. Also, water vapor will rapidly be added to the air due to evaporation from the relatively warm water surface. The air will become saturated, or nearly so. In fact, vapor may be added to such an extent

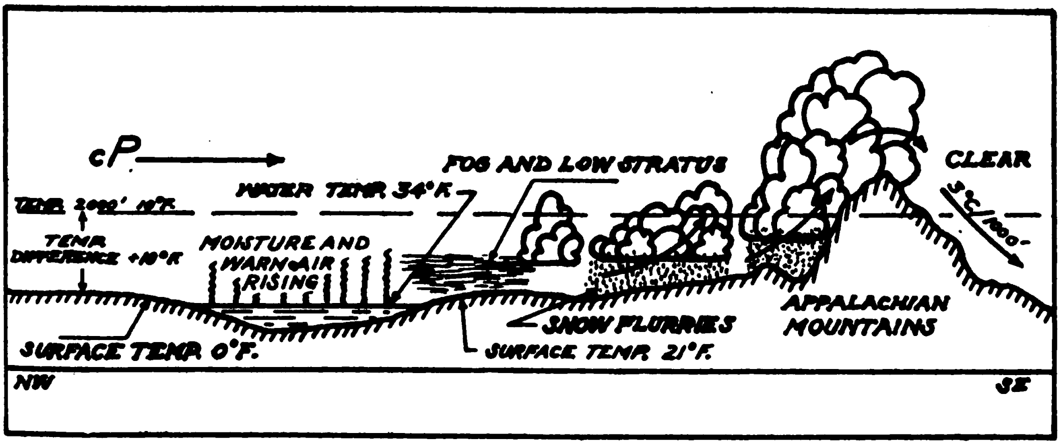


FIGURE 54.—cP air moving over Great Lakes.

that a phenomenon which might be described as "forced condensation" takes place. Evaporation may continue from the warm water even after the cold air has become saturated. Further evaporation will result in condensation. The condensation may appear as fog, but due to the instability of the air, the fog will soon be lifted to form a cloud.

(3) After crossing the lakes, the air again will flow over a cold, snow-covered surface. The surface cooling will increase the stability, and may produce fog. In addition, as shown in figure 54, the air may be subject to forced lift. By blowing up slope, instability may be released; the resulting towering cumulus clouds may possibly develop into cumulo-nimbus, although thunderstorms are rare in winter. However, rather heavy showers (rain or snow) would be expected in the mountainous area, and very severe icing conditions may also develop.

(4) Thus, we find a combination of factors making flying difficult. The terrain is rough and the visibility may be poor to higher levels. In

stratiform clouds, flying will not be rough; however, the pilot should be aware of the fact that lift over rough terrain may release the instability of the air. Rough flying (turbulence) may suddenly be experienced. Flying above the stratiform clouds will reveal whether or not such turbulence will exist in the form of cumuliform clouds rising from the stratiform deck. Such a cloud combination is an ideal setup for plenty of icing—lots of rime ice as well as intermittent regions of clear ice. It is easy enough to understand why many good pilots, who did not take proper account of weather, have had trouble in this area.

(5) What can the pilot do about such a situation? The first thing to do is understand it; the next is to try to avoid the worst part of it. It is not a good idea to try to fly low over such rough terrain; you may find that you cannot go ahead, and in the meantime it has closed in from behind. It might be possible to go high enough to avoid the worst weather but the best solution is to study the weather situation and try to go around the bad area. It might require a long detour, but avoiding such a combination is worth a long detour.

(6) On the eastern side of the mountains the air will descend, be warmed adiabatically, and the clouds be partially or completely dissipated. Under these conditions, as stated, flying weather would certainly be better on the *down wind side* than on the *up wind side* of the mountains. Remembering this point may some day indicate to you which way to go when you find yourself in troublesome weather.

(7) The above discussion points out the principles that apply to cold air moving over a warmer surface, or to any air that is cold, relative to the surface.

(8) In the United States a cold air mass occasionally reaches as far south as the Gulf of Mexico, but in the more southerly regions frontal activity plays an important part in determining the weather.

(9) The cold air eventually reaches the warm waters of the Caribbean Sea or Atlantic Ocean. A discussion of what happens follows.

66. cPk becoming mT.—*a.* In winter, when cPk air reaches the warm waters off the southern coasts of the United States, its temperature will usually be around 10° C. (50° F.). The temperature of the water is around 20° C. The air is rather unstable when it reaches the water surface. The same kind of thing happens as when the cold air flows over the Great Lakes except that the Great Lakes effect is localized while now the modification occurs over such a large area that a new air mass is formed.

b. The temperature and moisture content of the air will rapidly increase beginning in the low levels and will rapidly affect higher levels. It was noted previously that the formation of a good cP air mass re-

quired weeks (par. 19*b*). On the other hand, mT may form in about 36 hours. Thus, we would expect rapid changes in weather as cPk air moves over an mT source region.

c. The mT air which is formed over the Gulf of Mexico is usually not completely unstable, but potentially (conditionally) unstable. Although we would expect large clouds to develop over the Gulf, we do not usually find the thunderstorms that would be associated with air that is completely unstable. Thunderstorms may, of course, occur when there is any frontal activity over the Gulf. By potential instability we mean that the air is partly stable and partly unstable.

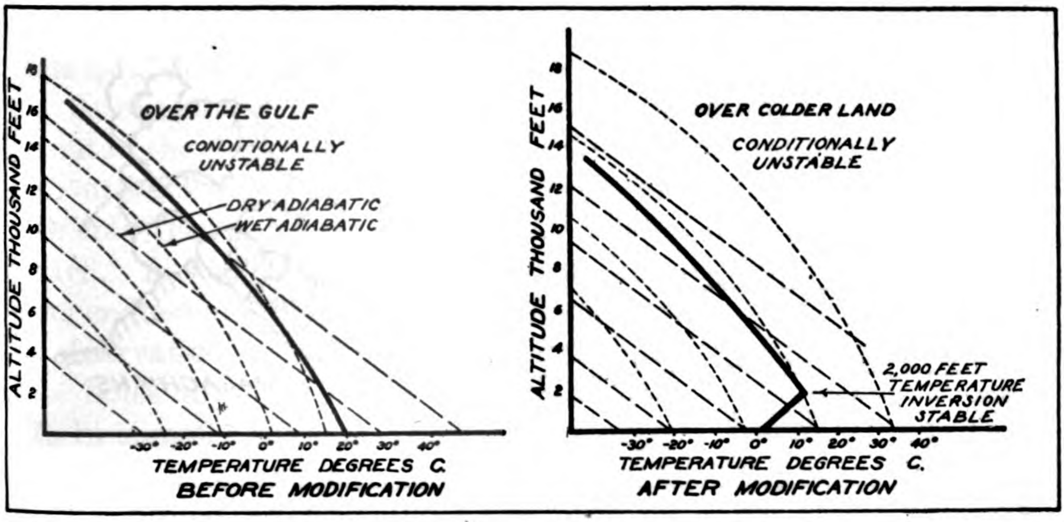


FIGURE 55.

This instability may be released by further heating at the surface (which occurs in summer) or by forced lift. mT air forced up the eastern mountains will result in much the same types of weather that were discussed under the Great Lakes effects.

67. mTw.—*a*. In winter, when the land surface is relatively cold, the mT air will move as mTw. It will be cooled from the bottom, which results in stability near the surface as shown in figure 55.

Due to the high moisture content of the air, this cooling usually results in condensation either in the form of fog or low stratus clouds, particularly at night when radiational cooling plays an important part (note fig. 50). In the more southerly latitudes, the heating effect from the sun usually causes sufficient convective lift to produce cumuliform clouds in the late afternoon.

b. Thus, disregarding the effect of fronts or terrain, under conditions as outlined, we would expect poor flying weather in the early morning but much improved by early afternoon.

c. The effect of frontal activity will be discussed in a later section. Terrain effects may now be considered under two general categories, gradual lift and rapid lift.

d. If mT air is forced over the mountainous country, as in the eastern United States, we would expect a stable layer near the surface which would probably result in fog, or other less serious restriction to visibility. We would also expect the release of the potential instability of the air at higher levels, which might produce thunderstorms, or at least large and troublesome cumuliform clouds. These

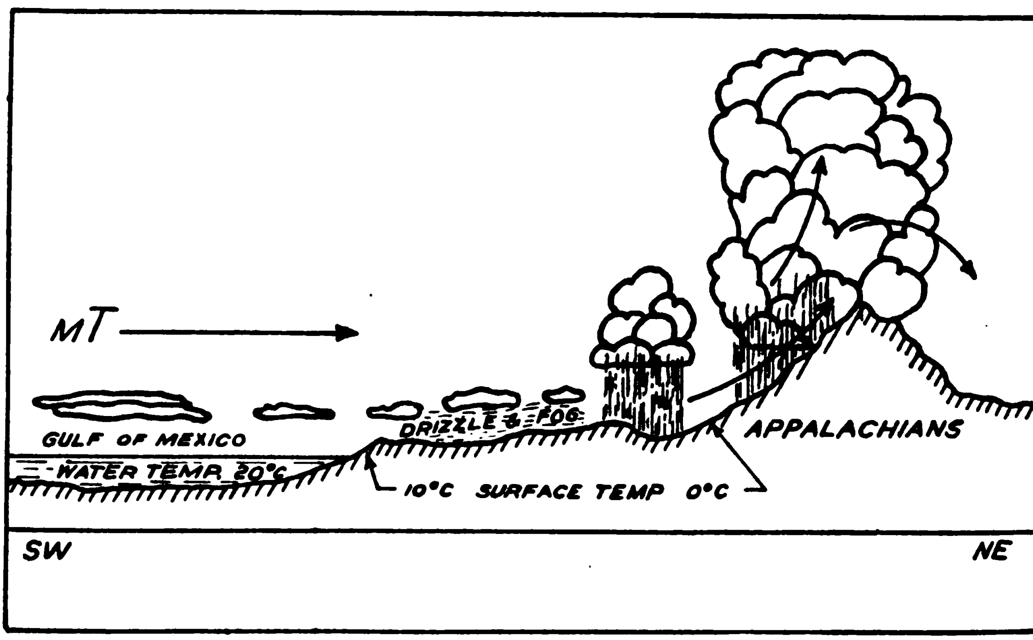


FIGURE 56.—mT air moving northeastward.

clouds might rise out of stratiform cloud systems, and therefore be encountered without warning. Icing might also be encountered. Thus, as in our consideration of the Great Lakes effect, we find a possibility of a combination of all the hazards; fog, thunderstorms, and icing (note fig. 56).

e. If mT flows up a gradual slope, as from the Gulf in a northwest direction toward the Great Plains area, we find different conditions. The cooling effect would be much the same. But the lift would not be rapid enough to release the instability. Apparently a slow lift allows the air to adjust itself to the normal stable state, whereas a rapid lift does not. Thus, with rather pronounced stability near the surface, the potential instability that existed in the air would not be released. Consequently, we would not expect the development of cumuliform clouds unless sufficient surface heating took place. As pre-

viously stated, fog or low stratus are to be expected, especially in the early hours of the morning. The stratus may persist throughout the day, covering thousands of square miles. However, if sufficient surface heating occurs, the stratus will be dissipated and cumuliform clouds may form in the late afternoon.

68. Summer weather.—*a.* Summer weather usually presents very little hazard to the smart pilot, except for occasional fog. On the other hand, the weather usually does not offer good concealment. Radiation fog or low stratus is common at night. Icing conditions can hardly be found except at high altitudes where there is plenty of room to get out of it on the bottom side. Thunderstorms, of course, are common, but they can usually be seen and avoided. Once in a while a cumulo-nimbus cloud may grow out of a stratiform cloud deck and be encountered unexpectedly. But the smart pilot will try to get out in the clear often enough so he will not run into a thunderstorm without knowing about it. Even the so-called squall line, associated with cold fronts, which will be covered later, does not present much hazard. A squall line is a continuous line of thunderstorms which looks endless and very formidable from the ground. However, careful observation, especially of the cloud form above, will usually disclose holes through which the airplane can be flown safely.

b. In summer we find the daily temperature variations playing an important part, and terrain plays a part relatively more important than in winter.

69. cP air in summer.—The source region of cP in summer is at high latitudes near the poles. This is about the same source region as for arctic air in winter. There is little flying activity in these regions, and due to the lack of military objectives and the infeasibility of military operations in these areas, there is little likelihood of extensive operations in the future.

70. mP air in summer.—There is no pronounced difference in mP in summer and in winter in the source except, of course, that it is somewhat warmer in summer.

71. mPk air in summer.—*a.* However, we denote an appreciable difference in the structure of mP air masses in summer as compared to winter after movement begins. Instead of being potentially unstable and accompanied by instability showers, we find that the air is much more stable and is accompanied along the Pacific Coast by prevalent sea fogs and persistent stratus clouds which usually dissipate in the late morning by surface heating. The sea fogs are largely a result of the passage of mP air as mPw over a cold water belt which arises along the California coast during the summer months.

b. As this mPw moves inland, the lower levels are heated by the warmer land areas and the air becomes mPk. This results in a decrease in stability in the lower levels. However, due to the dryness of the air aloft, this instability will not yield convective showers except occasionally in the high Sierra Nevada Mountains.

c. After passing over the mountain ranges, this air arrives on the eastern slopes with characteristics so similar to that found in cPk air that no differentiation is attempted.

72. mT air in source (summer).—The surface in the mT source is not much warmer in summer than in winter. However, the air flowing into the source will be much warmer in summer than in winter. Moisture, of course, will be added to the air lying over the water surface. Due to the smaller temperature difference in summer between the air and the water, instability will develop much more slowly. Consequently, we would expect milder weather in the mT source in summer than in winter.

73. mT air out of source (summer).—*a.* During the summer, the relatively low pressures over continental areas accompanied by the intensification of the high pressure areas over water surfaces causes an almost continuous movement of maritime tropical air over the south central and eastern United States. For this reason, maritime tropical air is more important in summer than in winter.

b. We find the properties of this moving air are similar to those in winter except that the air is warmer and more moist in summer. This produces a higher degree of convective instability which results in lower values of lift necessary to produce saturation. As the air moves inland in the day it will be passing over warmer land areas and therefore will be moving as mTk. This heating from below tends to release the convective instability with the result that cumulus clouds will always be found in the afternoon and under favorable conditions will produce local thunderstorms.

c. In areas near the Gulf and as far inland as the air will move during the night, fog or low stratus will form during the early morning hours. These stratiform clouds will dissipate during the morning hours by surface heating and cumuliform clouds will build up in the afternoon.

74. Monsoon.—*a.* As mentioned in the section on winds, the relation of land and sea temperatures has an important control over winds. The tendency is for the air to flow from the cold surface toward the warm surface.

b. A monsoon condition exists when the wind reverses from winter to summer. This is a large scale phenomena, and is most pronounced

in Asia. In winter, the cold air flows out of Siberia across India and China to the warmer ocean areas. In the summer the flow is completely reversed, with the relatively cool air flowing from the ocean areas toward the hot interior. When such a condition exists, the weather is decidedly seasonal. In India, for instance, there are many months in the year when there is no rain. Other months there are tremendous quantities of rain, sometimes averaging over 10 inches per day for a whole month.

c. A monsoon condition exists in the south central United States but to a less marked degree. The prevailing wind in winter is northwest, in summer southeast.

d. The factors that determine weather in a monsoon condition are no different from any other condition. However, the pilot should remember that there is a decided seasonal change. He should also bear in mind, that the things he learned about local weather conditions in winter will not hold for summer.

75. Sea breeze.—A sea breeze is simply a daily instead of an annual monsoon, and is a small scale matter. In the summer, along a seacoast, the land often gets considerably warmer than the water in the daytime. Due to radiational cooling it may become cooler than the water at night. In the daytime we frequently find an onshore breeze, from water to land; and at night an offshore breeze. The sea breeze will only affect an area a few miles from the coast, and will not occur at all if there is even a moderate opposing wind. However, in some special cases it may become of considerable importance to the pilot. Fog formed at sea may be blown inland, and seriously interfere with operations along the affected coast.

QUESTIONS

1. Give the three principal controlling factors of air mass weather.
2. How do we differentiate between a cold and a warm air mass?
3. How does cooling from below affect stability?
4. mPk air moving southward will be warmed in the lower layers. How will this affect the stability of the air mass?
5. Briefly, what will the flying characteristics and weather be in mP air as it moves across the western coast of Canada and the U. S. during winter?
6. What are the characteristics of cP air in its source region in winter?
7. Discuss the changes as cPk air moves over a body of warmer water such as the Great Lakes.

8. What will be the flying characteristics after the air has passed over the Great Lakes and moves farther south?

9. What are the characteristics of mT air in its source region in winter?

10. Discuss the flying characteristics in this air as it moves northward in the winter time.

11. What are the major hazards connected with air mass weather in the summer time? How do they affect the pilot?

12. Discuss the difference between a monsoon and a sea breeze.

Section X

FRONTAL WEATHER

76. General.—*a.* A front has previously been defined as the surface of the *cold air*. Below it is cold air. Above it is warm air.

b. The slope of the surface normally is from 1 in 50 to 1 in 300. For example, 100 miles from the surface front, the surface of the cold air would be anywhere between 2,000 feet to 2 miles above the earth,

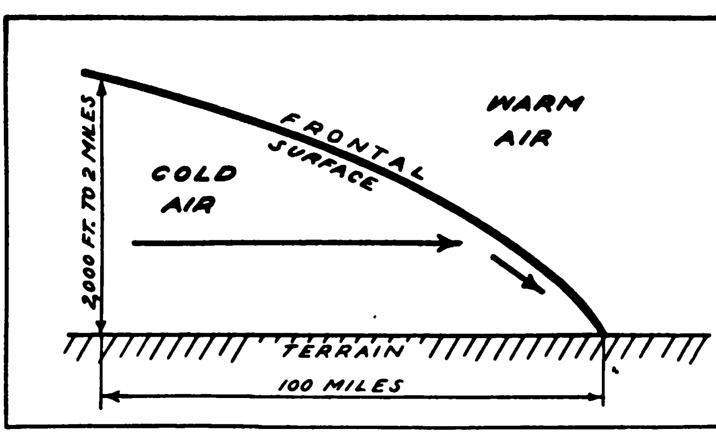


FIGURE 57.—Frontal slope 1-50 to 1-200.

depending on the slope (note fig. 57). The slope of the front, in conjunction with other factors, is of considerable importance to the pilot, and will be covered in detail in this section.

c. It is hard to visualize a front as a surface although, as previously mentioned, it acts very much the same as the surface of the earth. How it acts that way can easily be seen from the following diagram. Figure 57 shows a cross section through a front, with the slope much exaggerated. Suppose that a body of air were to bulge into the front; i. e. into the warm air. This air would be colder and considerably heavier than the warm air, so it would go down. It could not go up. Thus, if the cold air is moving toward the front faster than the front is moving, the only way it can go is down.

d. A similar situation in the warm air is shown in figure 58. If warm air were to bulge through the frontal surface, it would be warmer and considerably lighter than the cold air around it. Thus it would

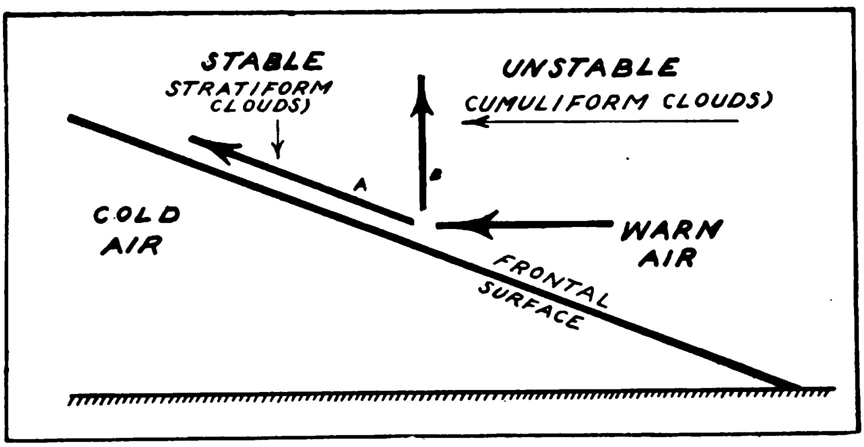


FIGURE 58.

go up. It could not go down. Thus, we can make general rules: any vertical component in the cold air near the front must be downward; any vertical component in the warm air near the front must be upward.

e. In figure 58, two vectors are shown—A and B. A represents the situation that would exist if the warm air were stable; B, the situation if the warm air were unstable.

f. Based on the previous study, certain conclusions are rather obvious. Any downward component tends to dissipate clouds. Thus, we would not expect clouds in the cold air near the front except those caused by rain falling from the warm air. Any cloud form that did exist would be representative of a stable condition.

g. We also know that upward currents tend to produce clouds. Thus, we would expect clouds in the warm air. Whether the clouds are stratiform or cumuliform depends upon the stability of the air (see fig. 58).

77. Stationary front.—*a.* Now let us see what would happen with pressure systems over North America in winter as shown in

figure 59. In the high pressure area to the north we see northeasterly winds bringing down cold, dry air. In the high to the south we find winds carrying warmer and moister air toward this same region. In the trough of lowest pressure the cold winds and the warm winds will come together. Consequently, we would find a front lying in the trough of low pressure. At the surface, the front would lie in the trough shown on the surface weather map. Aloft,

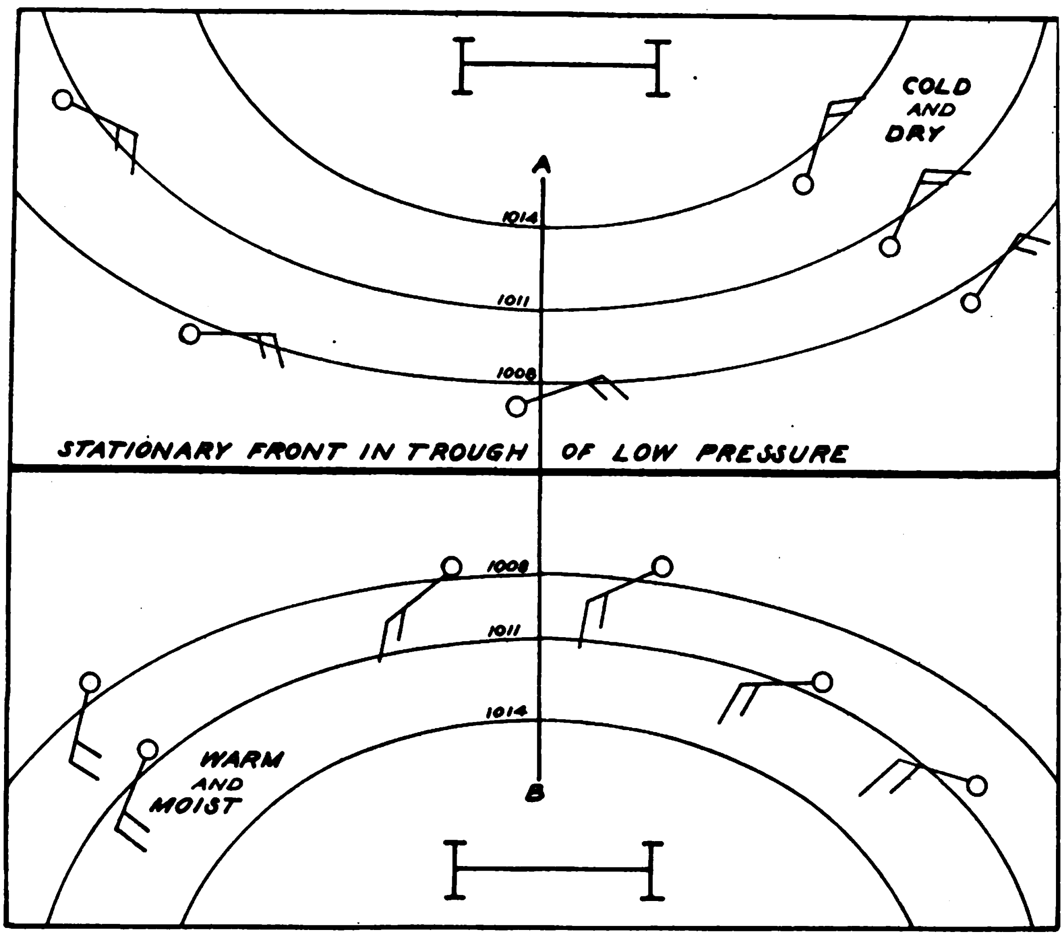


FIGURE 59.—Stationary front.

the trough and the front would be found farther north, as shown in figure 60. Such a front would normally have a slope of about 1 to 150; that is, 150 miles north of the surface front, we would find it to be about a mile high. The surface front is shown on the weather map by alternating blue and red line.

b. Now notice the wind direction relative to the front in figure 59. In both the cold and the warm air we find the air flowing either nearly parallel to the front, or with a slight component toward the front. If it is flowing somewhat toward the front, we must have a

slight downward component in the cold air, and a slight upward component in the warm air.

c. The effect in the warm air is exactly the same as though the warm air were blowing up a gradually sloping land surface. In this case the warm air is not very moist. After moving over a surface colder than the air itself, it would be stable. It will then resist lifting—a gradual lift will not render the air unstable. Also, the air being relatively dry, it will have to be lifted considerably before condensation will take place. Consequently, we often find, with this kind of front, no clouds near the surface front, but a band of clouds well to the north of the surface front—maybe 100 or 200 miles north.

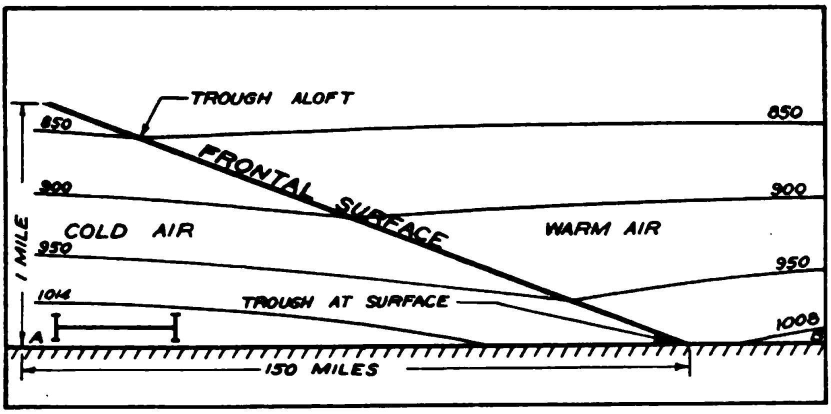
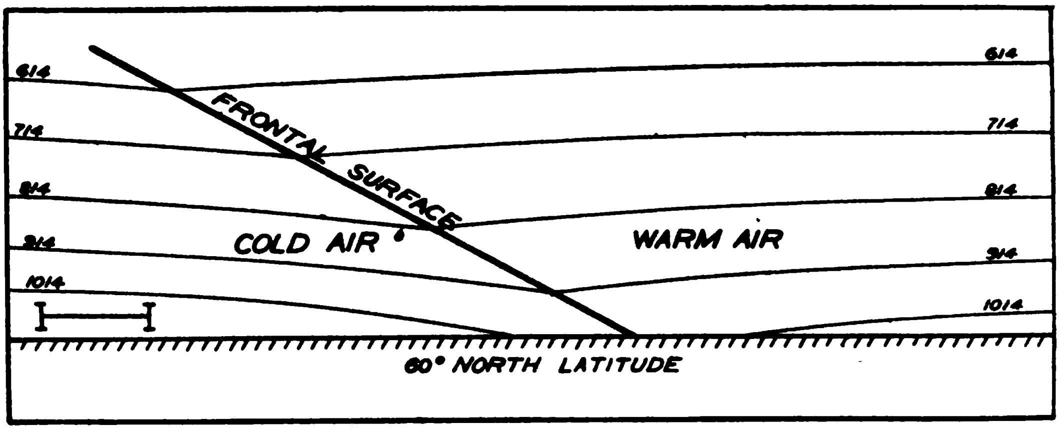


FIGURE 60.—Vertical cross section along AB of figure 59.

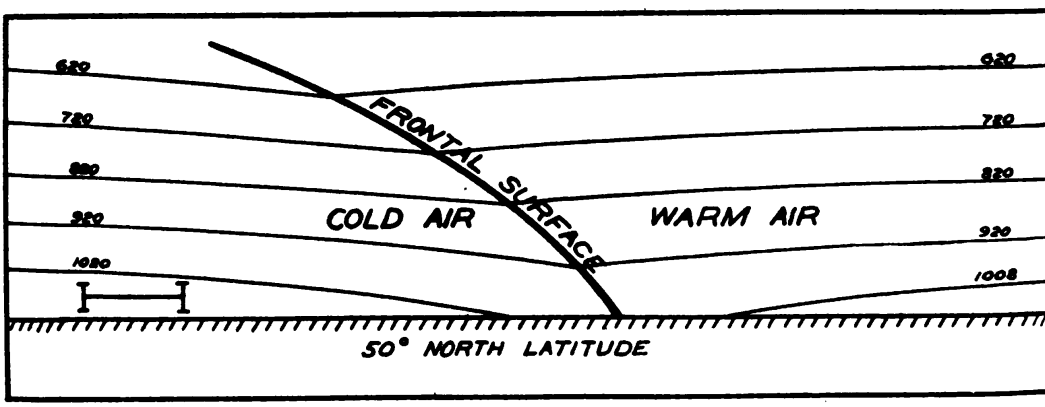
d. Now, let us investigate the cold air under the front. Since there will be no upward component in the cold air, the cold air itself can hardly produce any weather. However, where rain is falling from the warm air into the colder air, the relatively warm rain would rapidly evaporate into the colder air. Thus, we might expect stratiform cloud formation, not due to the action of the cold air itself, but due to the evaporation of rain from the warm air. Therefore, in the rain area we would expect low ceilings and visibility, and maybe fog.

e. What this means to the pilot is rather plain. The worst hazard that would be expected in the warm air would be a little icing. In the cold air below, the icing might be much more severe and also be associated with low ceilings and visibility. Obviously, then, a pilot flying through such a condition should stay up in the warm air.

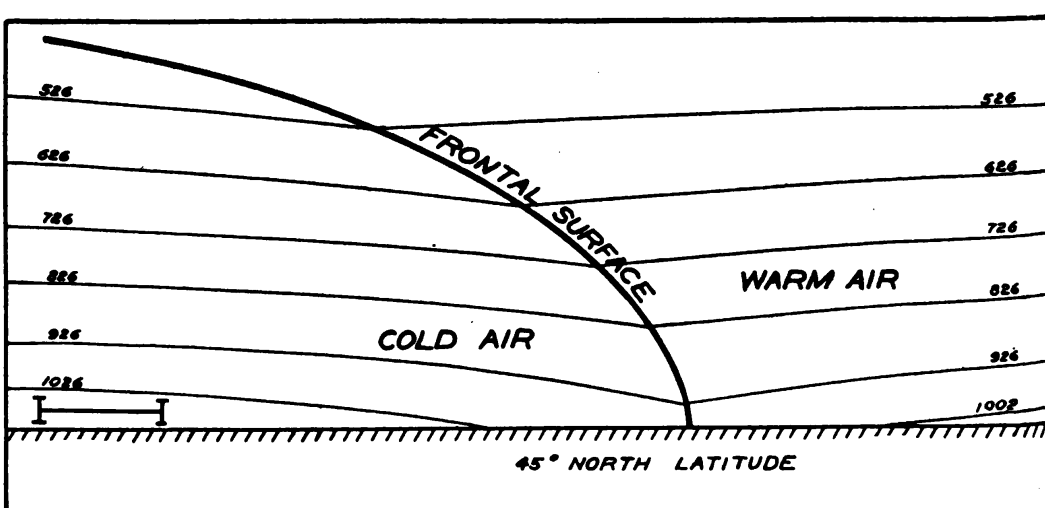
78. Cold front.—*a.* As more cold air is brought into the pressure system north of the front, eventually the pressure system will develop so that the front will move south, displacing the warm air. It then becomes a cold front. As it moves, surface friction will retard the



① Stationary front.



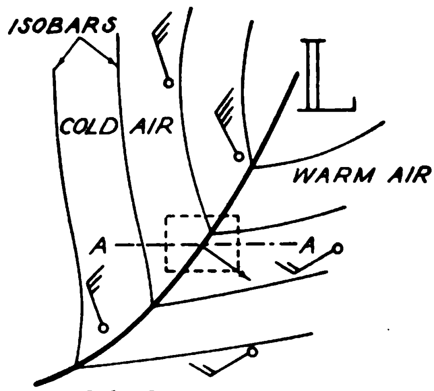
② Slow moving cold front.



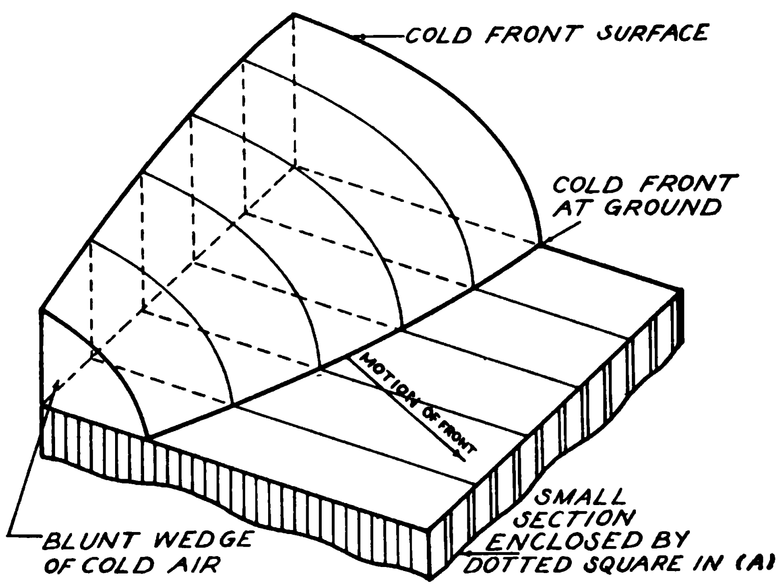
③ Fast moving cold front.

FIGURE 61.—Movement.

lower part of the front but not the higher part. Consequently the front will become steeper. The steepening of the front means that the wedge of cold air under the front becomes thicker; the thicker cold wedge of air produces a stronger pressure field behind the front. Thus, the movement of the front will be accelerated for some time. The faster it moves the steeper it gets, and the steeper it gets the more tendency there is for it to accelerate (note fig. 61).



① Cold front on map.



② Portion of earth and front in dotted area on ①.

FIGURE 62.—Cold front movement and associated surface winds.

b. By the time such a front moves into the United States, it will be a so-called fast moving cold front, moving 15 or 20 miles per hour. It will have a slope of about 1 to 50. The weather associated with such frontal activity is quite distinctive. This is the polar outbreak, or "cold wave", well known to people who live in the north central United States.

c. Previously we considered the wind relative to a stationary type of front. Now we must consider the winds relative to the moving front. Figures 62 and 63 show the winds that would normally be associated with such a system. So let us compare the weather with what we found on the stationary front.

d. As previously mentioned, the weather is determined by the warm air. Weather in this sense means flying weather, not just the kind of weather that is of importance to the man on the ground. The pilot is not worried about whether or not he should put his stock in the barn, or if the water pipes will freeze. Flying weather is further determined by the moisture content and stability of the warm air, and the rapidity of lift.

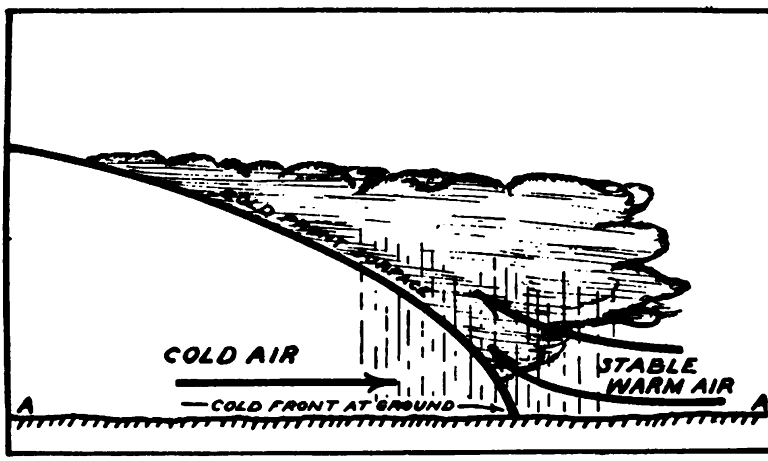


FIGURE 63.—Vertical cross section of cold front of figure 62 ① along the line AA.

e. As the cold front moves south, it will encounter air that is more moist and less stable. Thus, the same rapidity of lift would produce worse weather than farther north. In addition we find that the lift is much more rapid.

f. Regarding the stationary front, we would hardly expect a wind component of more than 5 miles an hour up the front. The air would have to travel about 150 miles up the front to reach an altitude of 5,000 feet, which would require at least 30 hours. Now, suppose that the cold front is moving 20 miles per hour. Even though the warm air has a component of 5 miles per hour away from the front, the *relative* wind will be 15 miles per hour up the front. It has to travel about 50 miles to reach an altitude of 5,000 feet, which in this case would take just a little over 3 hours. Thus, the air would be lifted as much in 3 hours in this case as it was in 30 hours in the case previously considered (note fig. 63).

g. If the warm air is stable, as it usually is in the northern part of the United States in winter, we would expect the same type of weather as found on the stationary front, but much more concentrated. The stratiform cloud deck in the warm air would appear possibly somewhat to the south of the front, and extend up over the frontal surface. The clouds would be much thicker vertically, although they might be concentrated in a relatively narrow band along the surface front—a band maybe 50 miles wide but extending hundreds of miles along the front. Precipitation also would be much heavier. The icing hazard, if any, would be considerably greater, but occur in a narrower band. Obviously, the proper way to fly through such a system would be straight through, as shown in figure 64.

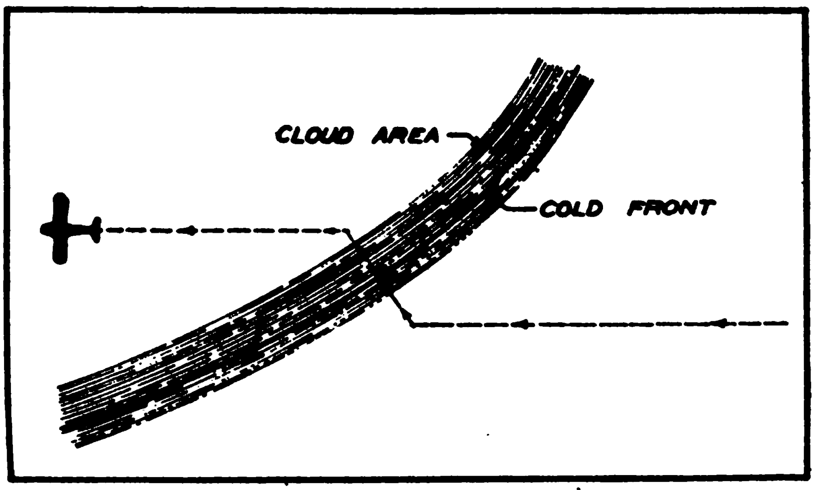


FIGURE 64.—Flight path through a cold front.

h. As the front moves farther south, it may encounter air that is potentially unstable. (This is the normal situation in summer, but not so common in winter.) We would then expect the rapid lift to release the potential instability in the warm air, and result in cumuliform clouds as shown in figure 65.

In winter we might expect large towering cumulus, but, except in the southern section of the United States, we would hardly get thunderstorms. We would, however, expect a heavy cloud mass along the front—long and high, but narrow. Under such conditions the precipitation would be much heavier than with stable air. There would also be much more danger of clear ice, where previously the main danger was from rime. In summer, under such conditions, we frequently find a squall line which is a long, narrow band of thunderstorms extending along the surface front. A squall line is not common in winter.

i. With either stable or unstable air we would expect to find a band in the cold air in which ceilings and visibilities are low. The band would be narrow—maybe 50 miles wide or less.

79. Wave development.—*a.* A front does not move smoothly and steadily, but by a series of surges. We know that a strong wind is not steady, but gusty. Water flowing swiftly will be rippled. As long as the surges in the front are so small that they do not appear on the weather map they mean nothing to the pilot. However, at some time in its southward movement, one or more large surges or waves will appear on the weather map. These waves are of great importance to the pilot.

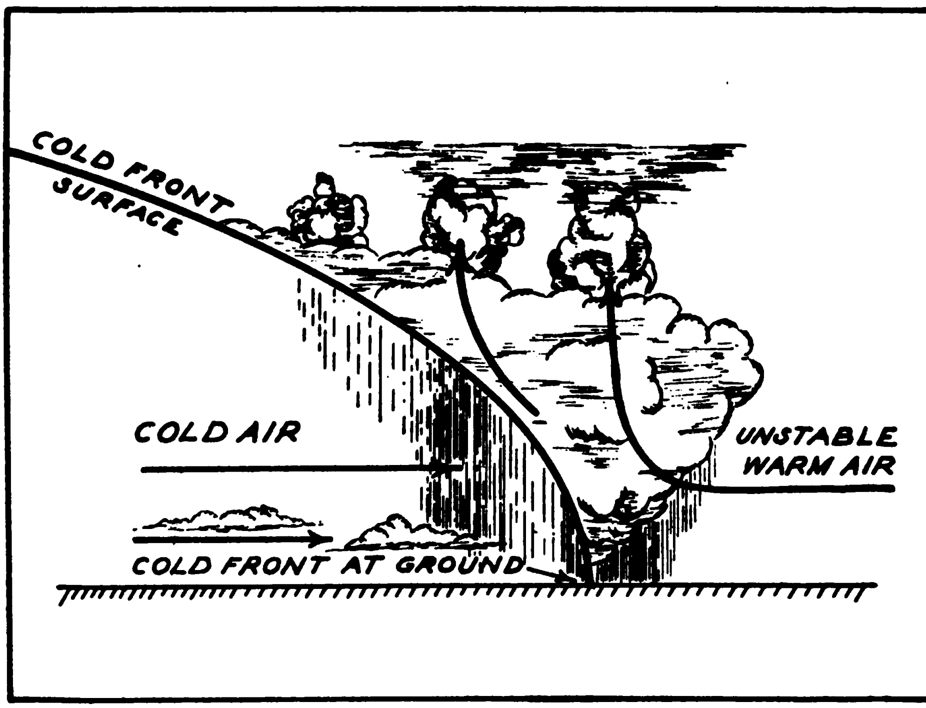


FIGURE 65.—Cold front with unstable warm air.

b. The reason for the formation of waves on a front is very involved and open to much argument, but the fact remains that waves do develop, and proof can be found by reference to weather maps. It is the job of the forecaster to decide when a wave is likely to develop. It is the concern of the pilot to know what kind of weather to expect if and when a wave does develop. In case the forecaster has not foreseen the wave development, it is important for the pilot to recognize its existence.

c. A wave begins with the retardation of a part of the cold front while the part of the front to the west is either retarded none what-

soever or very little. Thus we find one part of the front moving more slowly than a part to the west (note fig. 66).

d. A simple retarded or slow moving cold front produces weather of a milder but more extended type than is produced by the fast moving front. As the front slows down, its slope will become less steep.

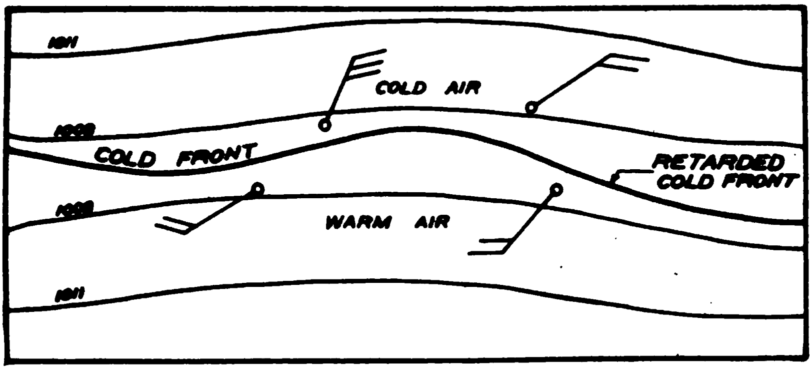


FIGURE 66.—Wave development, first stage.

Thus, the warm air is still subjected to more rapid lift than on the stationary front but less rapid than on the fast moving cold front. The resultant weather may be anything in between. Clouds will usually be stratiform and extend over a wide band back of the front, possibly 200 or 300 miles.

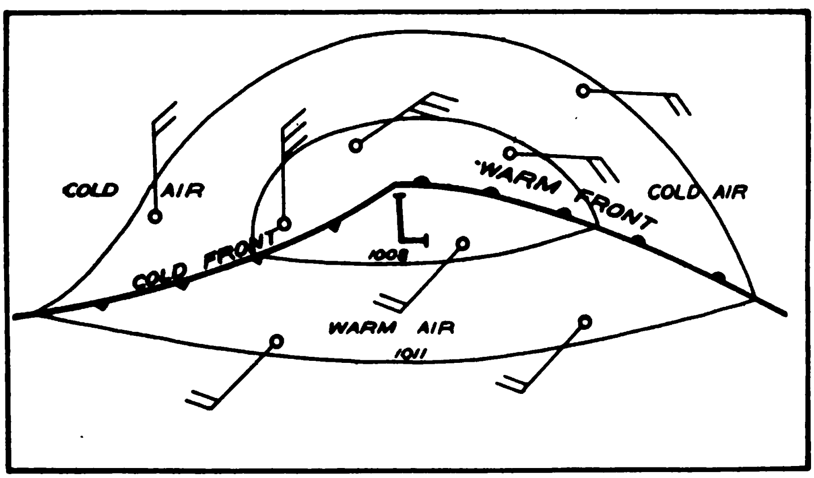


FIGURE 67.—Wave development, second stage.

80. Warm front.—*a.* However, reference to weather maps will show that a wave development is always associated with the formation of a low pressure area, with its center at the crest of the wave (see fig. 67).

Furthermore, as the wave develops, the low pressure area will intensify, the pressure decreasing and the isobars moving closer to-

gether. This results in winds quite different from those associated with a simple fast moving cold front. This situation will eventually result in the retarded section of the cold front actually reversing its direction, and moving northward as a warm front (note figs. 67 and 68).

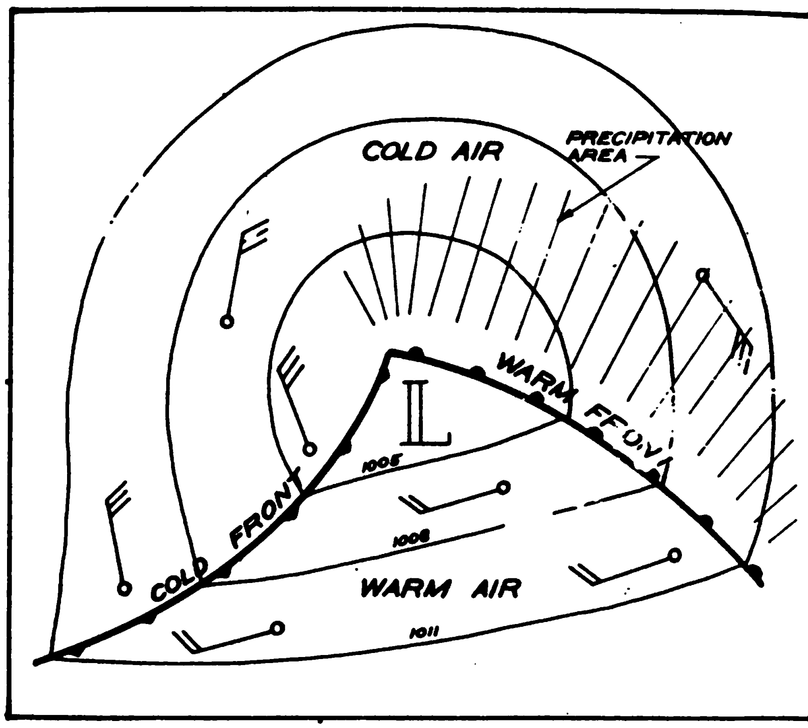


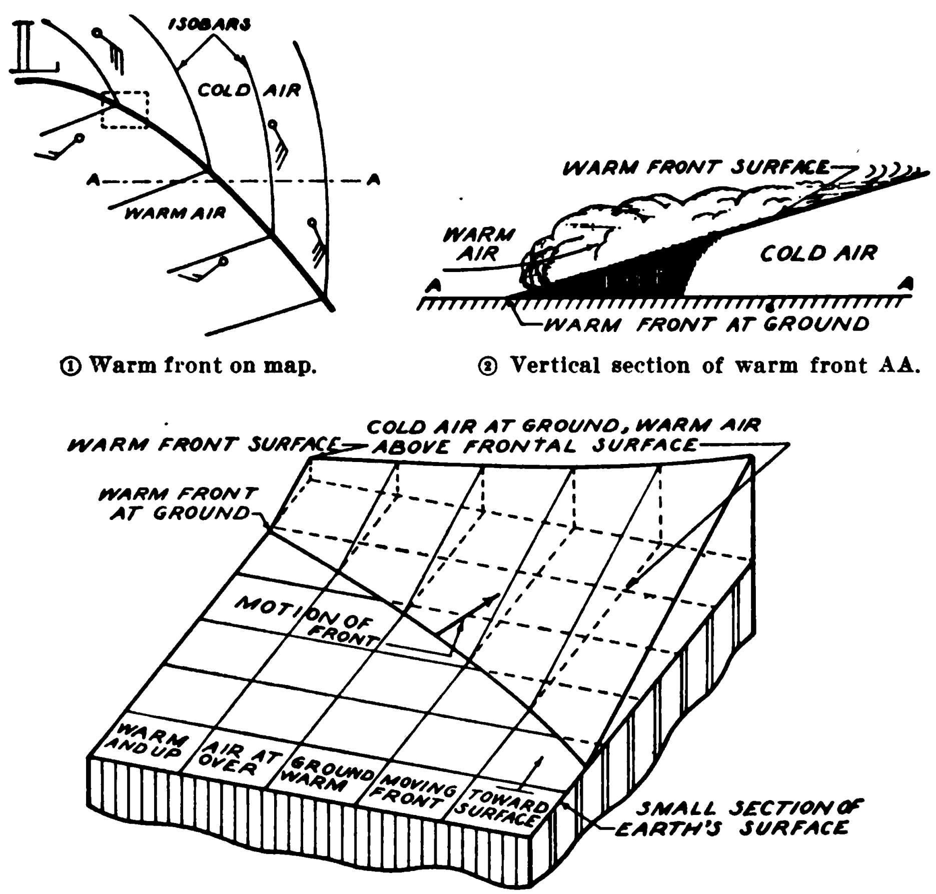
FIGURE 68.—Wave development, third stage.

b. The warm front will give us weather of a still less intense sort but covering a much wider area. The warm front cloud system may extend as far as 500 miles to the northward which is now ahead of the front. Associated precipitation, of course, will cover a similar area (see fig. 69).

c. Icing may occur in connection with warm fronts, as with cold. But if it does occur, it will be mainly of the rime type, sometimes rime and clear mixed. It may be encountered over a wide area. Clear ice could possibly occur in the cold air below the front; if it did, it could hardly form very fast. Figure 70 shows where icing might be encountered under conditions in which clouds have not developed in the cold air; figure 71 shows where it might occur under conditions when clouds have developed in the cold air due to evaporation from the warm rain. These figures are worthy of study.

d. In case icing is encountered under such conditions, the best procedure is usually to change altitude. If it is practicable to descend to levels at which the temperature will be above freezing, it is usually

best to go down. If not, it would be better to go up. How high would depend on the situation; it would be necessary to keep going up until the icing stops, or is reduced so that it can be handled by deicing equipment. Bear in mind, however, that this is only one type of icing condition. Other conditions might indicate a change in direction.



① Warm front on map.

② Vertical section of warm front AA.

③ Portion of earth and warm front in dotted square in ①.

FIGURE 69.

e. The major hazard associated with warm fronts is not icing, but fog. Drizzle or light rain often falls from the warm air into the colder air over a very large area, 500 by 1,000 miles in extent. The warm rain will readily evaporate into the colder air, producing clouds which may extend down to the surface as fog. Low ceilings and visibilities will be most common as well as most troublesome at night, but occur also during the day (see fig. 72).

f. The pilot should bear in mind, when operating in such conditions, that it may be necessary for him to detour several hundred miles to reach a point at which a safe landing can be made. Before he starts on his mission he should know which way to go in case fog does form,

and then recognize the condition long enough in advance to get into the clear, if necessary, for a safe landing. When you switch onto your reserve gas supply, it is often too late to detour.

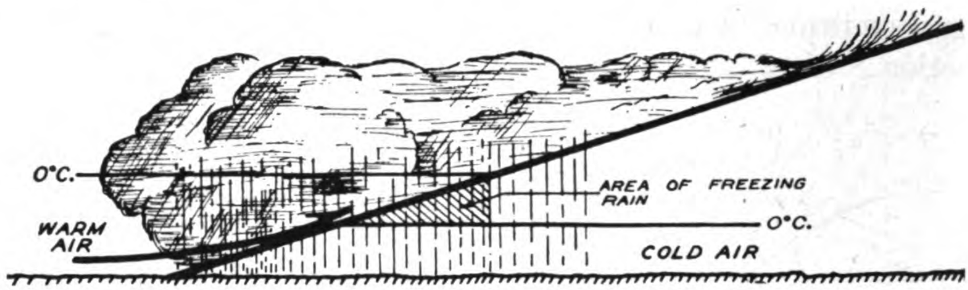


FIGURE 70.—Supercooled rain in the cold air.

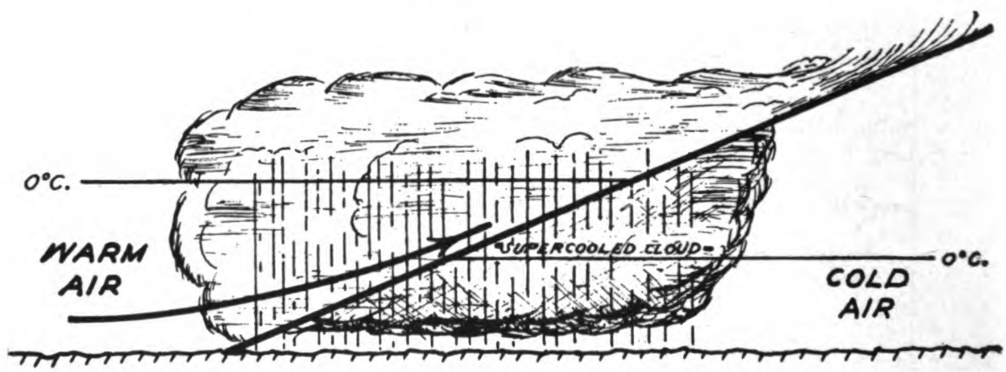


FIGURE 71.—Supercooled cloud in the cold air.

FIGURE 72.—Warm front fog.

g. In addition to icing and fog, thunderstorms may be encountered in a warm front situation if the warm air is unstable. The forced lift will release the instability of the warm air, causing thunderstorm clouds to be superimposed over the stratiform cloud system. Likewise, superimposed upon the continuous precipitation of the stratiform clouds will be the intense showers from the cumulo-nimbus clouds (note fig. 73).

h. A pilot making a continuous flight in the stratiform clouds of a warm front system may encounter thunderstorm conditions (severe turbulence and icing) without warning. The smart pilot will occasionally fly above or below the clouds to see what might be lurking ahead in the clouds. The danger may then be avoided by going around the thunderstorm clouds.

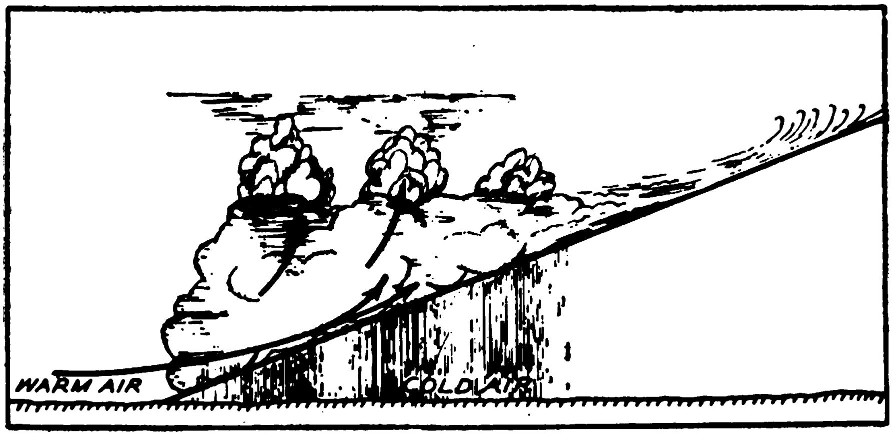


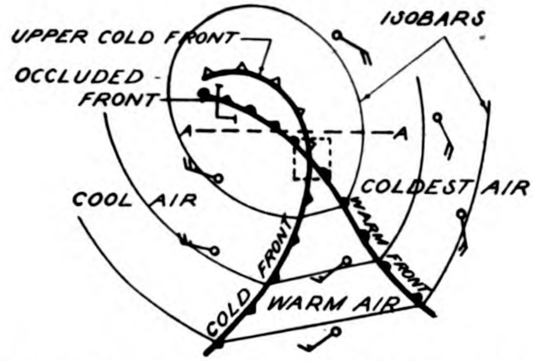
FIGURE 73.—Warm front thunderstorm.

81. Occlusion.—*a.* A warm front cannot move as fast as the wind component toward the front since some of the air will rise over the frontal surface. This is different from the situation with a cold front where the front must move with the same speed as the wind component into the front.

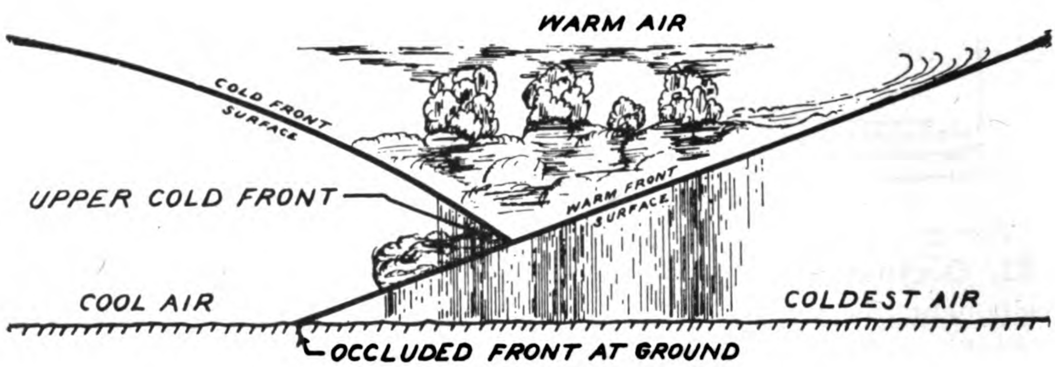
b. Consequently, when a wave develops, the cold front will move faster than the warm front and eventually overtake it. This results in a so-called occluded front, which is really a combined cold and warm front. Here we find three types of air, warm, cold and colder. The warm air will rise over the cold, and the cold over the colder. Figure 74 pictures a warm front occlusion with the coldest air to the east. Figure 75 pictures a cold front occlusion with the coldest air to the west.

c. The weather associated with an occlusion is often quite troublesome, with a combination of warm front and cold front weather. We may find more than one stratiform cloud deck covering a very large area, with cumuliform clouds superimposed in and on top of the stratiform.

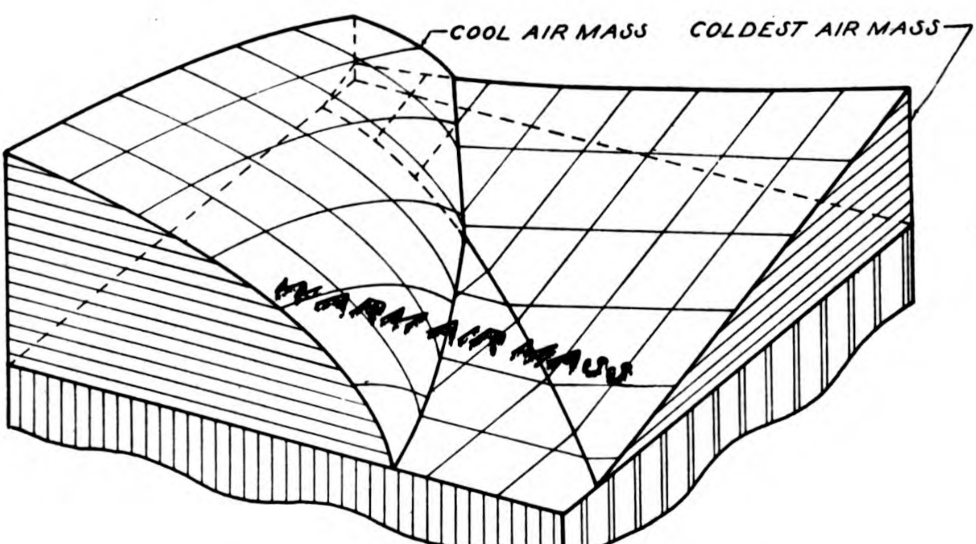
d. The kind of weather is similar to that produced by terrain, and of course depends on moisture content and degree of stability. A warm front associated with mountains and a warm front associated with a cold front, as in the occlusion both offer trouble. Warm front ordinarily means reduced visibility at low levels. Cold front or moun-



① Occluded cyclone on map (warm front type).



② Vertical cross section along AA.



③ Portion of earth and air above dotted square in ①.

FIGURE 74.—Occlusion (warm front type).

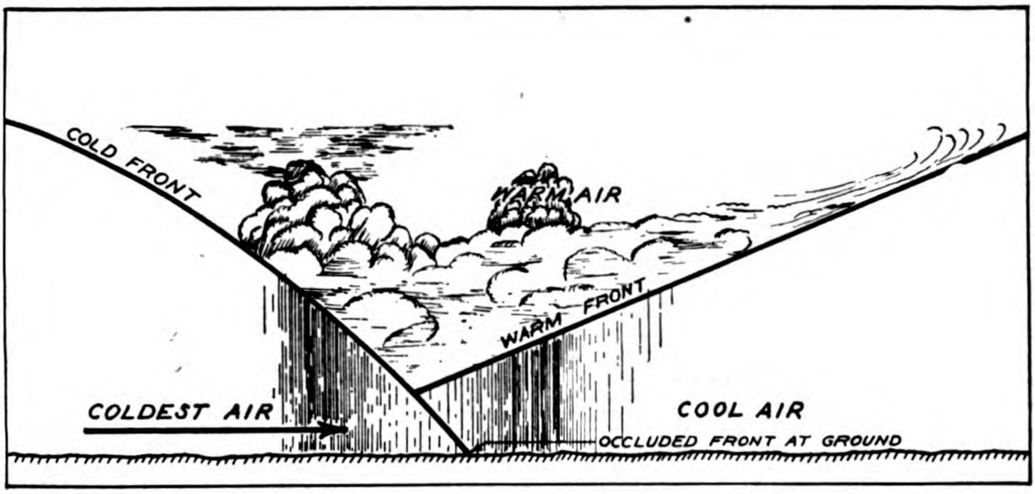


FIGURE 75.—Occlusion (cold front type).

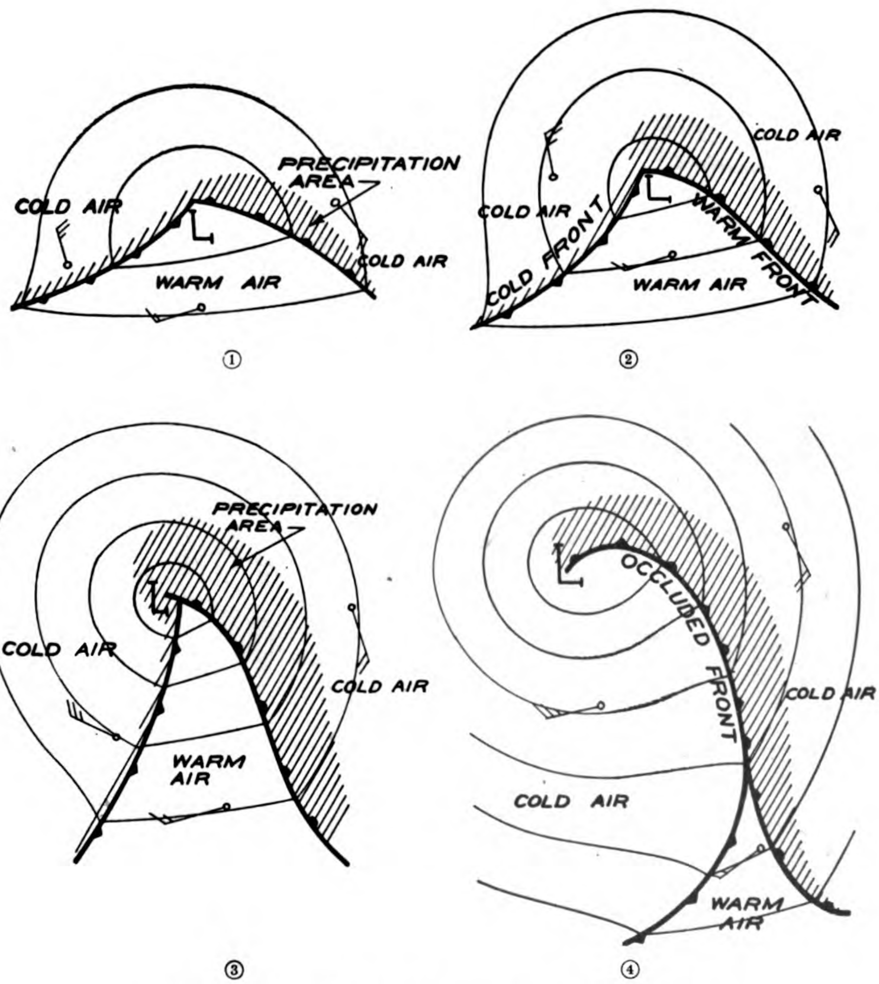
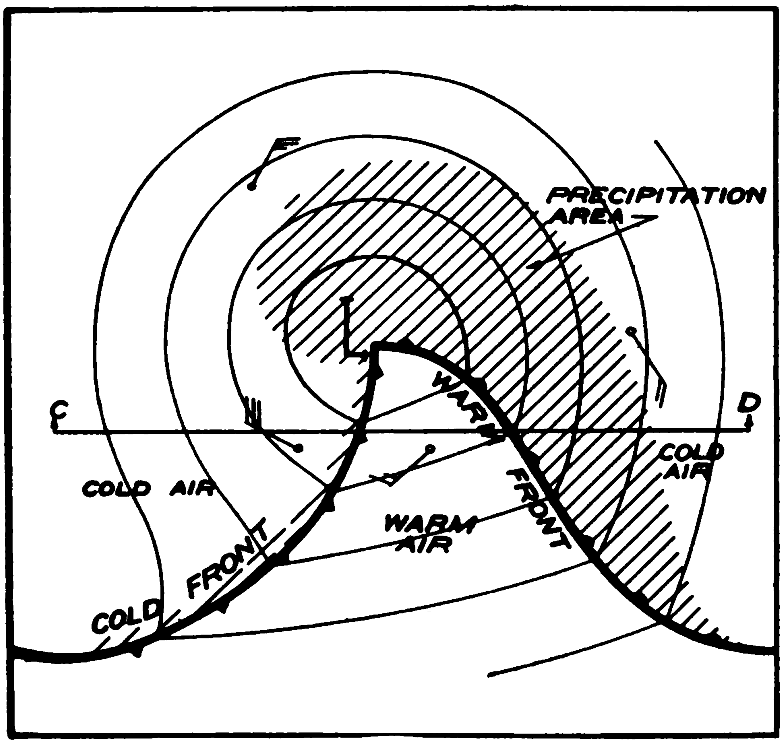


FIGURE 76.—Wave development and occlusion.

tains, with unstable air, means rough flying aloft. Rough flying in clouds or rain means that if there is an icing hazard it will be more serious than is found in smooth air. Also, thunderstorms or large



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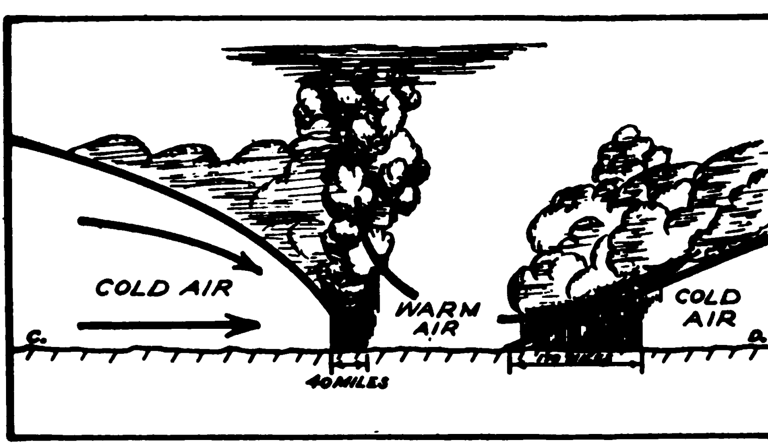


②

FIGURE 77.—Wave on weather map, and vertical cross section through wave along line CD.

cumuliform clouds of less intensity may develop, and can easily be encountered with little or no warning.

e. To carry the wave activity to its conclusion, eventually the warm air will be squeezed to high levels, the low pressure area will dissipate and the frontal activity will decrease and finally stop. The occlusion

is the beginning of the dying out process of the storm area. Figure 76 summarizes wave development and occlusion. Figure 77 ① shows a wave as it would likely appear on a weather map. Figure 77 ② is a vertical cross section taken along line CD of figure 77 ①.

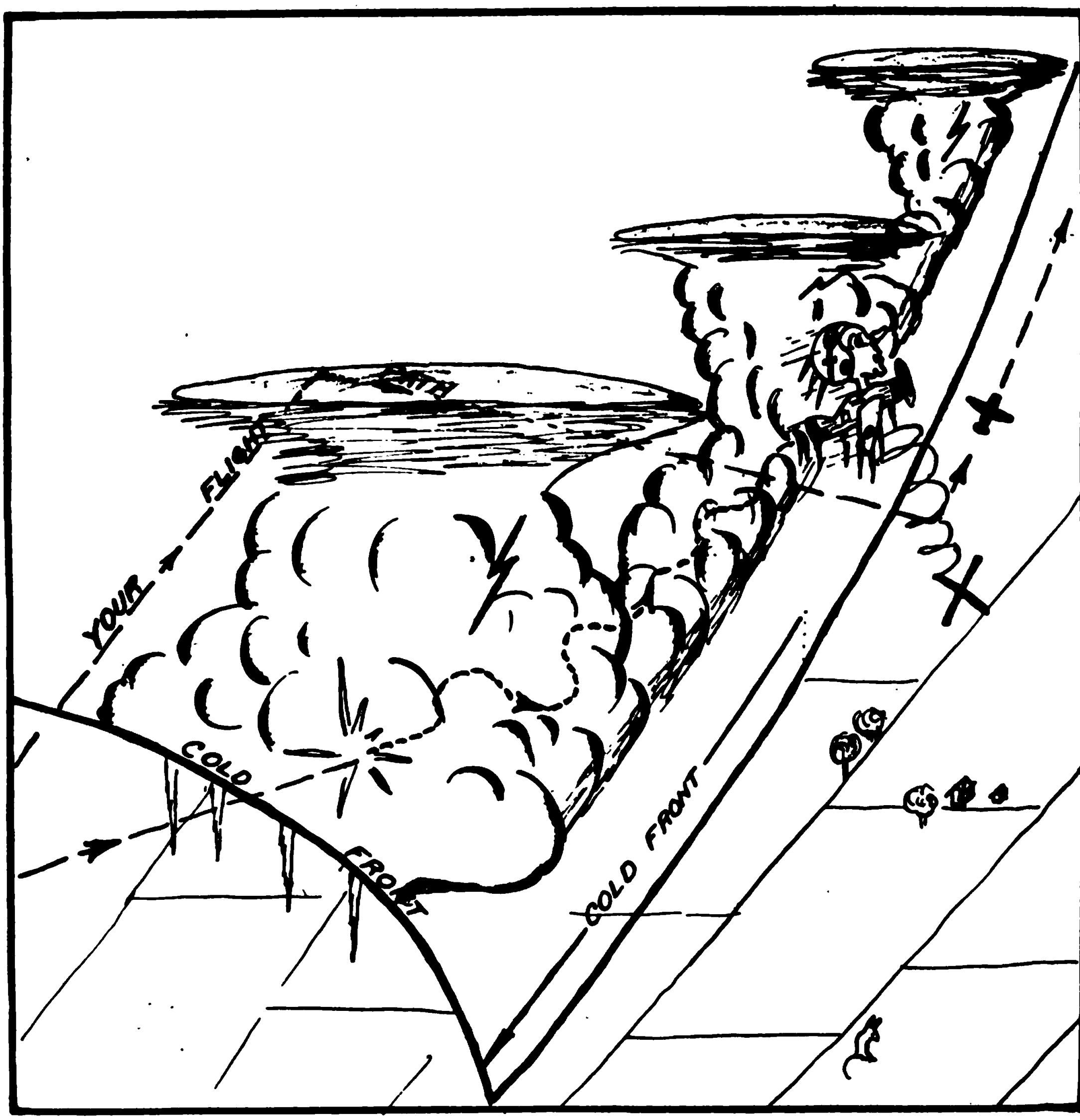


FIGURE 78.—Knucklehead will never have enough experience.

82. Unattached warm fronts.—Warm fronts which are not associated with cold fronts whatsoever may also exist. This may occur, for instance, when warm air flows from the Gulf of Mexico up into the United States. Unless associated with the kind of cyclonic activity associated with the wave on the cold front, the front will not be very distinct and will not produce much weather. In such a case the front has only an incidental effect on the weather, which is determined more by the factors discussed in the section on air mass weather than on the frontal effects.

83. Fronts aloft.—Fronts may also exist in the upper air. Frequently a front is forced up over the Rocky Mountains from the west, and then proceeds for some distance to the east before again descending to the surface. Sometimes they do not reach the surface again, but seem to dissipate aloft. Such fronts may cause considerable weather activity, but it will usually be high above the surface. Consequently, great trouble to the pilot seldom results.

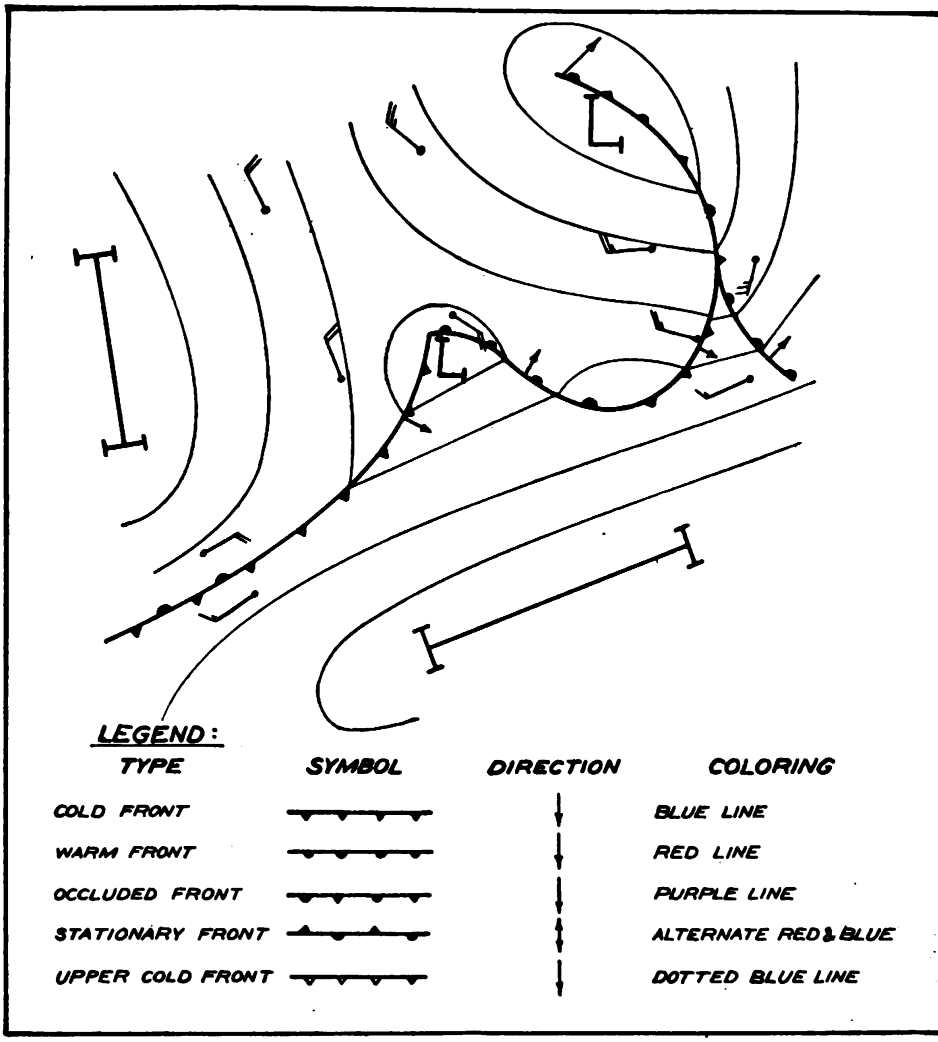


FIGURE 79.—Designation and coloring of fronts on weather maps.

84. Squall line.—*a.* The previous discussion has been primarily concerned with winter fronts. Even in winter, if the warm air is sufficiently moist and unstable, thunderstorms may develop. Several storms may extend in practically an uninterrupted line along the cold front. This is what is called the squall line, but it is a more common phenomena in summer when the warm air is more moist and unstable than in winter. The storm develops in the same way as discussed under

terrain effects except that here the lift is provided by the frontal surface instead of the surface of the earth.

b. With the range of modern aircraft, the pilot can usually find a break in a squall line through which he can fly safely. If for some reason it is necessary to fly through a squall line where no break can be found, remember to go through the shortest way which is perpendicular to the front (see fig. 64). Even the shortest way, you will wish you were out of the storm long before you are. This is the kind of flying that experienced pilots avoid whenever possible, and it takes only one flight through a squall line to gain this kind of experience.

c. Often a weak point in the front can be found by studying the cloud form aloft. Observing the cloud form at high levels will often indicate which way to go much better than low level observations.

d. Figure 79 shows the method by which the various fronts are designated on the weather map and the manner in which the forecaster colors them.

QUESTIONS

1. Define front. What is the relative position of the warm and cold air?
2. In which air mass are the clouds associated with a front usually found? Why is this?
3. Relative to the pressure system, where is the front found?
4. At a warm front, where is the area of precipitation?
5. What determines the type of icing found along the front?
6. Discuss the formation of fog in connection with a warm front.
7. Briefly, what is a squall line? Is it safe to fly through?

SECTION XI

FOG

85. General.—*a.* Fog is one of the most common weather hazards encountered by pilots. Fog is defined as any cloud which covers the ground and reduces horizontal visibility. Since a cloud may be defined as a suspension of liquid water in air saturated with water vapor, the same definition can hold for fog. Low stratus, which is formed by the same process as fog, is just as great a hazard even though it does not cover the ground. If the cloud is more than 50 feet off the ground, it is not fog, but low stratus. The mere change of name, or the difference in cloud base of a few feet, is small consolation to the pilot who finds his visibility close to the ground obstructed.

b. The amount of liquid water in fogs and clouds has been measured and found to be between 0.1 and 5.0 grams per cubic meter of air. The average fog droplet is quite small, about .0016 inch in diameter. Rain drops are from 10 to 100 times larger.

c. The following are the symbols used on weather maps for various fog conditions:

Ground fog
Light fog
Thick or dense fog
Fog with sky discernible
Fog in patches

d. The following visibility criteria are used in determining the intensity of fog. The symbols given are those used in the airways weather sequences as reported on the teletype circuit.

Terms	Criteria	Visibility reported as
Light (F−)	Objects visible at ⅝ mile or more	¾, 1, 1¼, 1½, etc., miles.
Moderate (F)	Objects visible at 5/16 but not at ⅝ mile	½ mile.
Thick (F+)	Objects visible at ⅕ but not at 5/16 mile	¼ or ⅕ mile.
Dense (FF)	Objects not visible at ⅕ mile	⅛ or 0 mile.

e. These same visibility specifications are used for determining the degree of intensity for ground fog and ice fog.

86. Saturation of air.—*a.* The curve AB in figure 80 represents the amount of water vapor required to saturate air at any given temperature. Notice that at higher temperatures the air can hold more water in the vapor state. Any point to the right of the curve represents air of a given temperature and water vapor content such

that the air is not saturated. The sample of air as expressed by the point X has a certain temperature and humidity. We may move the point X up on the diagram, which means adding more water vapor; i. e., raising the dew point temperature, while keeping the temperature the same; or, we may move the point to the left by lowering the temperature while the water vapor content and dew point temperature remain the same. The temperature at which the air becomes saturated when cooled is known as the dew point temperature. The result is that in either case we move the point X to the curve AB. The air along AB is saturated with water vapor and is at its dew point temperature and any further cooling will yield water as a result of condensation, hence fog. As the cooling continues, the dew point will fall because more and more vapor has condensed.

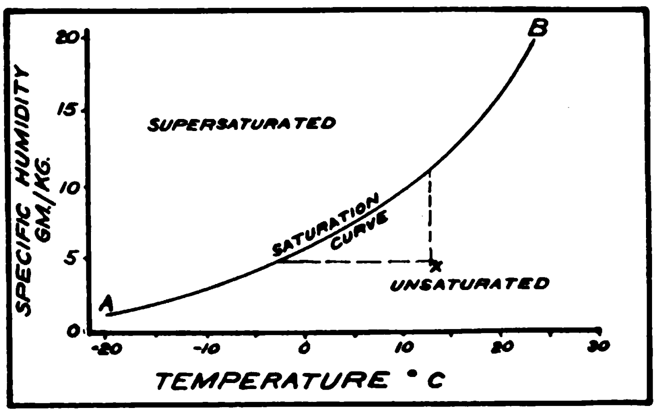


FIGURE 80.—Saturation curve.

b. Raising the dew point temperature is usually accomplished by the evaporation of water from falling rain or by passage of a body of air over a water surface. A high dew point is a characteristic of maritime air masses. Continental air masses which may move slowly over such water surfaces as the Great Lakes show a considerable change in dew point temperature. It should be noted that at higher temperatures a very small increase in temperature means that much more water vapor can be accommodated. A much larger change in temperature would have to be made at colder temperatures to accomplish the same increase in vapor content. All of which means that it requires more heating of the sun to dispel a fog at 40° F. than it does at 60° F., even though the liquid water content of the fogs is the same in both cases. A pilot may expect to wait a longer time for a fog to dissipate in winter than in summer, partly because of the cause mentioned above and partly because there is less insolation during the winter than in the summer.

87. Condensation nuclei.—There are present in the atmosphere very small particles known as condensation nuclei around which water vapor condenses. These nuclei are microscopic in size and are hygroscopic; that is, they have the property of absorbing water vapor from the air. The familiar calcium chloride, which is placed on country roads and tennis courts in the summer to keep dust down, is hygroscopic. The most common condensation nuclei in the atmosphere are sulfur trioxide and phosphorus pentoxide, products of the combustion of coal which contains sulfur and phosphorus as impurities. Common salt, sodium chloride, which is in the air as a result of the evaporation of sea spray acts as condensation nuclei, but is not as potent a factor as the others. The importance of these condensation nuclei can be realized from the fact that perfectly clear air can be saturated eight times; that is, have a relative humidity of 800 percent before condensation takes place.

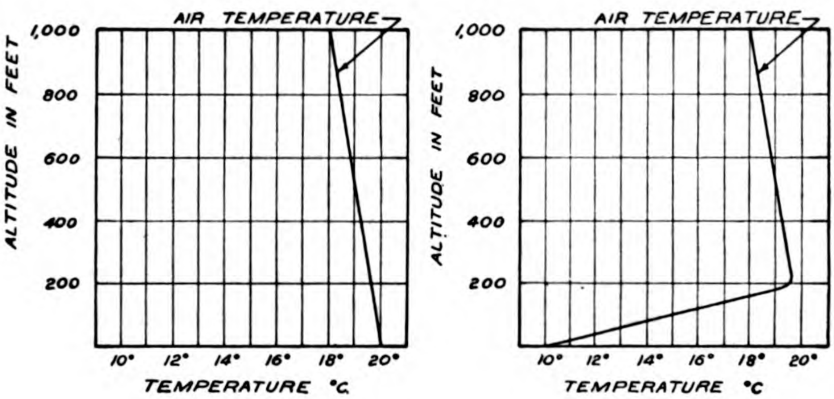
88. Haze.—*a.* Haze is a concentration of condensation nuclei, dust, and smoke particles. These particles may be so thick that distant objects appear blue or indistinct. The visibility is reduced by haze; the less the visibility, the more dense is the haze. Visibility will be less looking away from rather than in the direction of the sun because the particles reflect sunlight.

b. Haze is very closely related to the formation of fog. As the air approaches saturation, prior to the appearance of fog, the haze becomes more dense. A pilot noticing the thickening of the haze will know that the air is becoming more saturated and will know that fog could easily form if the other conditions are favorable.

89. Winds.—*a.* Wind velocity plays a very important role in fog formation, not so much because of its horizontal velocity but because of the vertical currents which result from the friction between the air and the earth's surface. The strength of this turbulence depends on the wind velocity; the higher the velocity, the greater the effect of the turbulent vertical mixing. There is also thermal turbulence, or convection currents which are caused by the sun's heating during the day.

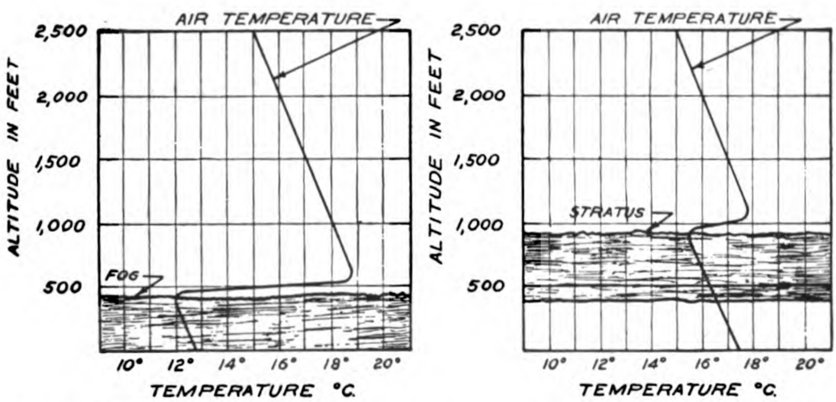
b. If there were a complete calm, a layer of fog, if formed, would be only a few inches deep. A light wind produces some turbulence which serves to mix succeedingly deeper fog layers. However, winds of high velocity are so turbulent and tend to mix the air so thoroughly that the fog layer is dissipated or lifted off the ground. The resultant cloud layer is called low stratus if the base is more than 50 feet from the ground; otherwise, it is called fog. Both fog or low stratus are hazards to the pilot since either prevents his seeing the ground.

90. Air mass fogs.—*a*. Air mass fogs occur within a given air mass and are formed when the layer of air close to the earth's surface is cooled by contact with a colder surface below. Wind turbulence causes some vertical mixing which deepens the fog layer; however, since this cooling makes the air next to the ground heavy, no large scale mixing results and the fog persists. This cooling causes an inversion which means that the temperature actually increases with height. Figure 81 ① shows the air temperature decreasing 2° C. per 1,000 feet and figure 81 ② shows an inversion after cooling has occurred.



① 1800 o'clock. ② 0600 o'clock.

FIGURE 81.—Cooling.



① Wind 7 miles per hour. ② Wind 20 miles per hour.

FIGURE 82.—Fog and low stratus.

b. When a slight wind velocity exists, the vertical mixing destroys the lower part of the inversion. It is in this layer below the inversion that fog forms. The inversion marks the top of the fog layer; the stable air as indicated by the inversion acts as a lid on further mixing. Figure 82 shows examples of fog and of low stratus.

c. Fogs will dissipate when vertical mixing destroys the inversion above them. High wind velocities may be sufficient. Dissipation

normally occurs when the sun's heating produces a threefold effect. The heating produces convection currents. The heating supplies the necessary heat of vaporization to change liquid to vapor. The air temperature is also raised so that the air can accommodate this newly formed vapor. Since heating is the greatest enemy of fog formation, we expect a minimum of fog in the daytime and a maximum at night and early morning.

d. There are several types of air mass fogs. Each gets it name from the particular manner in which the air is cooled to the dew point or saturated to condensation. They are radiation fog, advection fog, up slope fog, and steam fog.

91. Radiation fog.—*a.* Radiation fog, which sometimes occurs as ground fog, is caused by the radiational cooling of the earth's surface at night. It forms only at night and over a land surface. It never forms over a water surface. Reports of ground fog show that it is usually scattered over a wide area.

b. The earth continues to radiate heat after the sun goes down, and since after sunset the earth does not get any heat from the sun, the surface begins to cool because of this heat loss. As the earth cools, the layer of air close to the earth is cooled by conduction. In case of a calm, this cooling by conduction would affect only a very shallow layer of air, a few inches deep, because air is a poor conductor. Wind of low velocity, not more than 8 miles an hour, causes slight turbulent currents. This convection is enough to spread the fog through succeedingly deeper layers. As the nocturnal cooling continues, the air temperature drops further, more moisture is condensed, and the fog becomes deeper and more dense.

c. Radiation fog is common in high pressure areas. The pressure gradient in these areas is small and the resultant wind velocity low. We always associate good weather with high pressure areas, and clear skies are frequent. High pressure areas move slowly, and when they pass over any water surface, the lower layers of air pick up moisture, thus raising the dew point. One can often follow the movement of a high pressure area across the United States by noting the stations reporting ground fog on the morning weather map.

d. Ground fog requires special conditions for its formation. The air must have a reasonably high relative humidity such that the cooling during the night will saturate the air. Of course, it forms only at night over a ground surface. Because nocturnal cooling is hindered by any sort of cloud cover, a clear sky is favorable. A thin layer of cirro-stratus has been known to prevent fog formation. The wind must not be too strong, yet have high enough speed to give some turbu-

lence. The maximum velocity at which ground fog may exist is 8 mph. So, in summary, we find that ground fog formation is favored by air with high relative humidity, nocturnal cooling over land, clear skies, and light winds.

92. Advection fog.—*a.* Advection fog is the name given to fog produced by air in motion or fog formed in one place and transported to another. This type of fog is formed when the air is transported over a colder land or water surface. Cooling from below takes place, and gradually builds up a fog layer. The cooling rate depends on

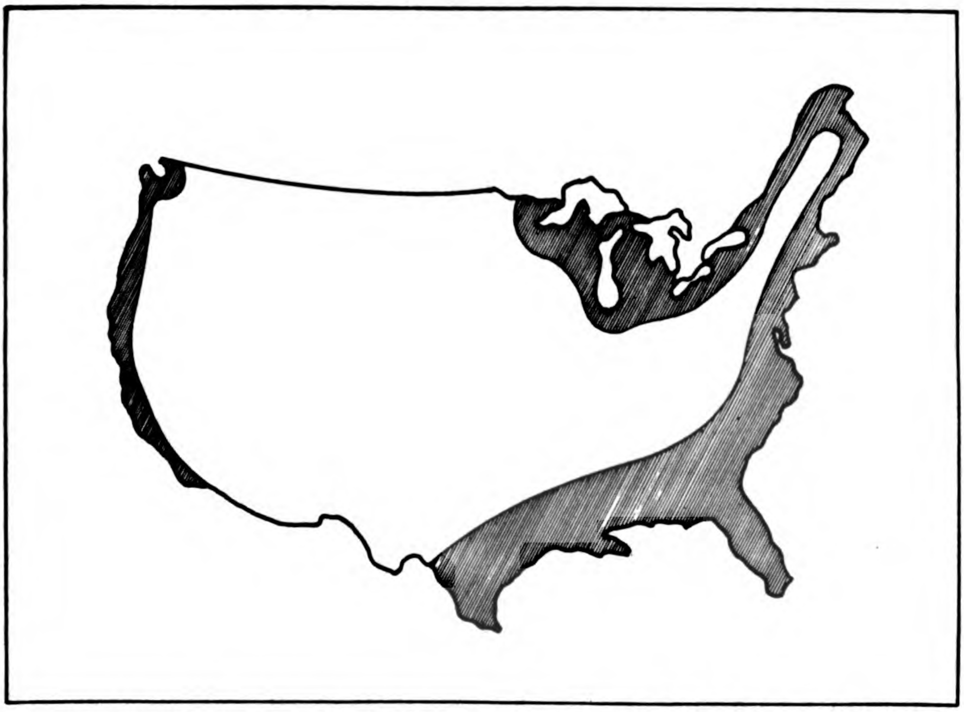


FIGURE 83.—Areas in United States most often affected by advection fog.

the wind velocity and the difference between the air temperature and the temperature of the surface over which the air travels.

b. Sea fog is always of the advection type and occurs when the wind brings moist air over a colder ocean current. Maritime air usually has a high relative humidity and not very much cooling is required to cause fog. The greater the difference between the air temperature and the ocean temperature, the deeper and more dense the fog. Sea fog may occur during the day or night. Some wind is necessary, not only to provide some vertical mixing, but actually to move the air to the place where it is cooled. Sea fogs have been maintained with wind velocity as high as 30 mph. Most advection fogs are found at velocities between 5 and 15 mph. Sea fogs exist at such high wind velocities because of the lesser friction effect over a

water surface. Winds of equal velocity produce less turbulence over water than over land.

c. The famous Grand Banks fogs are formed when air moves from the Gulf Stream over the cold Labrador current. Likewise, the ocean temperature near San Francisco is much lower than that of the surrounding water. This contributes to the California fog.

d. Sea fogs tend to persist for long periods of time. In the first place, they are quite deep and dense, and in the second place, the temperature of the ocean surface changes very little during the day. Consequently, it is not surprising to hear of sea fogs which have lasted for weeks.

e. Land advection fog is found near large bodies of water; that is, along sea coasts and large lakes. Onshore breezes bring in this maritime air over a land surface which has cooled by radiation at night. Also, fogs may form over the ocean and be blown over the land, day or night (see fig. 83).

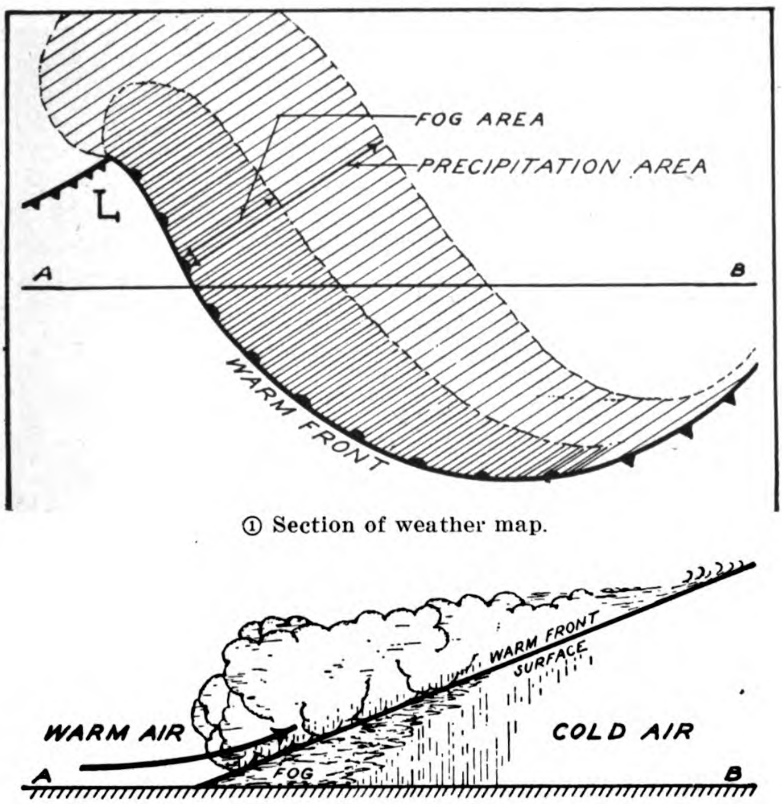
f. Land advection fog cannot exist with as high a wind velocity as the sea type because of the greater turbulence. If only a slight amount of cooling is necessary to cause condensation, even a cloud cover may permit the land surface to cool enough to cause fog. This type of fog dissipates in much the same fashion as radiation fog because it is over a land surface. However, since it is usually deeper, it requires a longer time to dissipate.

93. Up slope fog.—*a.* Clouds are formed by the adiabatic cooling of rising air. There is a type of fog formed by the same process, called up slope fog. From its name, we can see that it is formed when warm, moist air is forced up a slope by the wind. The rising air cools at the adiabatic lapse rate. The cooling is almost entirely adiabatic since there is very little conduction to the surface of the slope. The air must be stable before it starts its motion so that the lifting will not cause convective currents which would dispel the fog.

b. Some wind velocity is needed, of course, to cause the up slope motion. The fog is usually found where the air moves up a gradual slope. These fogs are deep and require some time to dissipate. The most common fog of this type is called Cheyenne fog, and is caused by anticyclonic circulation in the Mississippi Valley which produces fog on the eastern slope of the Rockies.

94. Steam fog.—Steam fog, or sea smoke, occurs within air masses, but unlike other air mass fogs which are formed by the cooling of the air temperature to dew point, steam fog is caused by saturating the

air through evaporation of water. It occurs when cold air moves over warm water. Evaporation from the surface of the warm water easily saturates the cold air, causing fog. It rises from the surface like smoke. It should be noted that the actual condition, heating cold air over a warm surface, tends toward instability. In order for such fog to persist, there must be an inversion above the surface which prevents the smoke from rising very high. This type is most common in northern latitudes. Familiar marsh or swamp mists are steam fog.



① Section of weather map.

② Vertical cross section along AB.

FIGURE 84.—Warm front fog.

95. Frontal fogs.—*a.* Frontal fogs are another hazard which the pilot must add to his list of weather troubles associated with fronts. The actual fog occurs under the frontal surface in the cold air mass. It is due to the evaporation of the falling rain. This addition of water vapor gradually saturates the air (fig. 80). Precipitation falls from the lifted warm air through the cold air. Evaporation from the rain will continue as long as the temperature of the raindrops is higher than the temperature of the air even though the cold air is already saturated. Naturally, the upper regions will become saturated first

because the temperature and dew point are lower at the higher altitude. As the evaporation from the rain continues, a layer of clouds will begin to build down from the frontal surface. Eventually, this cloud will extend down to the ground and become fog, as indicated in figure 84. During the day there may be enough turbulence caused by solar heating to keep this cloud off the ground. However, after dark, because of dying convection currents and the nocturnal cooling of the air, the ceiling drops very suddenly. It is this sudden closing in after dark that makes this type of fog so dangerous. Pilots may be confronted with zero ceilings, almost without warning.

b. Cold fronts usually move so rapidly, have such narrow bands of precipitation and high wind velocities, that cold front fog is comparatively rare. The warm front type is the more common and

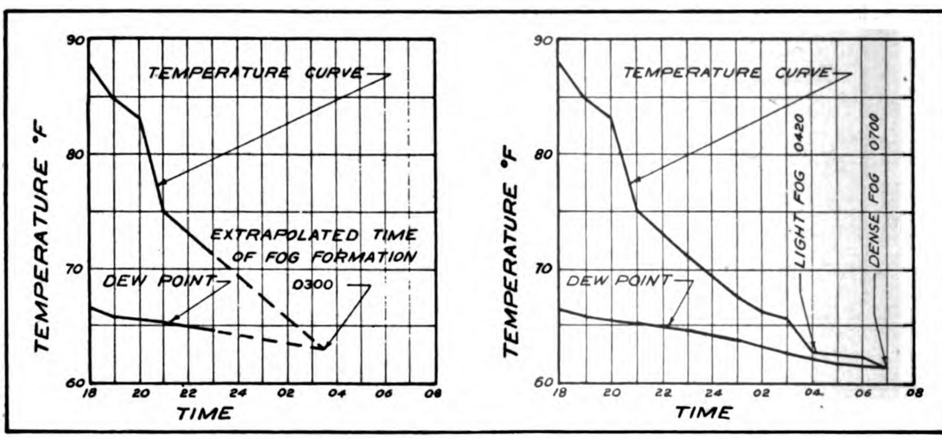


FIGURE 85.—Forecasting the time of fog formation.

the more dangerous. Frontal systems are quite extensive and warm frontal fog may cover a wide area as indicated in figure 84. As it also extends from the ground to the frontal surface, it is very deep. The clouds above the frontal surface also slow down the dissipating effect of solar heating. All these factors make warm front fog the worse possible type to encounter. Flights which terminate under warm fronts should be made only after a careful inspection of the weather map, noting dew points and rainfall. Conditions in this system are worse from sunset until sometime after sunrise.

96. Forecasting formation of fog.—*a.* A pilot flying at night should keep in mind the hazard of fog forming at his terminal. Most fogs are caused by a combination of radiation and advection. As already discussed, night is the time such a fog would be expected. Every pilot with a night flight will be on the lookout for any signs of fog.

b. The pilot can make a reasonably accurate forecast of the formation time of fog if he can determine at what time the temperature and dew point will come together. By using the method outlined below, a pilot can make a good estimation of that time. The only material needed is a chart of some kind on which temperature and dew point can be plotted against time. The graphs in figure 85 show how this is done. On the graph to the left were plotted temperature and dew point against time up till 2300. From there the

FIGURE 86.—? ? ? ? ?

curves were extrapolated to the point where they came together, which is 0330 or the time fog would be expected to form. The pilot would have sought an alternate port if his flight were going to take him into that field after 0330. The graph on the right shows what actually happened; the fog did not form until 0420, and dense fog formed at 0700.

97. Summary.—*a*. Fog may be formed by cooling the air to dew point temperature or by raising the dew point by the evaporation from warm water which will saturate colder air. Condensation nuclei are necessary. For air mass fogs caused by cooling, a wind of

slight velocity is needed to effect mixing. The important fogs and the conditions favorable for their formation are as follows:

(1) Conditions favoring the formation of radiation fog are, air with high relative humidity, nocturnal cooling aided by clear sky, dry air aloft, and light wind, 3 to 8 mph.

(2) Advection fog forms when warm moist air flows over a colder surface and is usually found over the ocean or near the seacoast.

(3) Up slope fog forms due to the adiabatic cooling of rising air.

(4) Steam fog is caused by cold air being saturated by evaporation from warm water surface.

(5) Frontal fog results from saturating the cold air under the frontal surface by evaporation from the warmer falling rain.

b. Many pilots would still be flying today had they realized the importance of knowing that the air is cooler and nearer saturation at night and that fog is largely a *night time phenomena.*

QUESTIONS

1. Define fog. How is it related to low stratus?
2. In what two ways may the air become saturated?
3. Give two methods by which the dew point temperature might be raised.
4. What are condensation nuclei? What is their function in the atmosphere?
5. Briefly, how is wind velocity related to fog formation?
6. How does a temperature inversion affect fog formation?
7. Give five essential conditions for the formation of radiation fog.
8. What do we mean by advection fog? Where is it most common?
9. Up slope fog is caused by the adiabatic cooling of rising air. Explain.
10. All fog is classified as either air mass type or frontal type fog. What is the difference? Give three examples of air mass fog.
11. How is frontal fog formed? Where is it found?
12. Why is fog more apt to form after the sun goes down?
13. You are on a cross country flight in the late afternoon of a warm clear day. You receive a radio report that the temperature is 74° F. and the dew point is 71° F. at your destination. The sun will go down one hour before you are due to arrive at your destination. Is there a possibility of any hazardous condition? What would you do?

SECTION XII

THUNDERSTORMS

98. General.—*a.* A thunderstorm, as the name implies, is a storm characterized by the presence of lightning and thunder. These two elements, however, fail to be truly indicative of either the storm's intensity or its magnitude and are the result, rather than the cause of the storm.

b. A thunderstorm is a thermodynamical machine in which potential energy is rapidly transformed into kinetic energy and expended in the production of violent vertical air currents, torrential rain, hail, gusty squall winds at the surface, lightning and thunder. Obviously, a thunderstorm is one of aviation's greatest hazards.

c. To the aviator, a thunderstorm presents a problem that cannot be disregarded. Encountered in flight, such a storm should be avoided by flying around, flying below the base, if the ceiling is high enough, flying over the top if oxygen equipment is present, or by a precautionary landing until the storm passes. Flight through a thunderstorm should not be made unless absolutely necessary. Since the safety of the pilot, his passengers, and his cargo will depend upon the selection of the correct procedure, it is essential that the pilot thoroughly understands the peculiarities of various types of thunderstorms. However, it is desirable first to treat thunderstorms in general and establish some of the fundamental conditions and processes favorable for thunderstorm development.

99. Thunderstorm cloud.—Thunderstorms occur with cumulo-nimbus clouds. In figure 87, a cross section of such a cloud is pictured, featuring many of the dangers that make flight within and near the cloud hazardous.

a. Description.—(1) Cumulo-nimbus clouds are heavy masses of cloud, with great vertical development, whose cumuliform summits rise

in the form of mountains or towers, the upper parts having a fibrous texture and often spreading out in the shape of an anvil. The base resembles nimbo-stratus, looking very wet and menacing. The transition from water and ice cloud to ice cloud near the top is apparent by the change from well defined outlines to hazy indistinct borders.

(2) Obviously, a cloud with such vertical development can only be produced in unstable air. Convective (up) currents must be strong and of great extent in order that such a cloud be produced. The anvil top is due to the spreading out of the vertical (convective) currents by a stable layer aloft, which those currents cannot penetrate. This

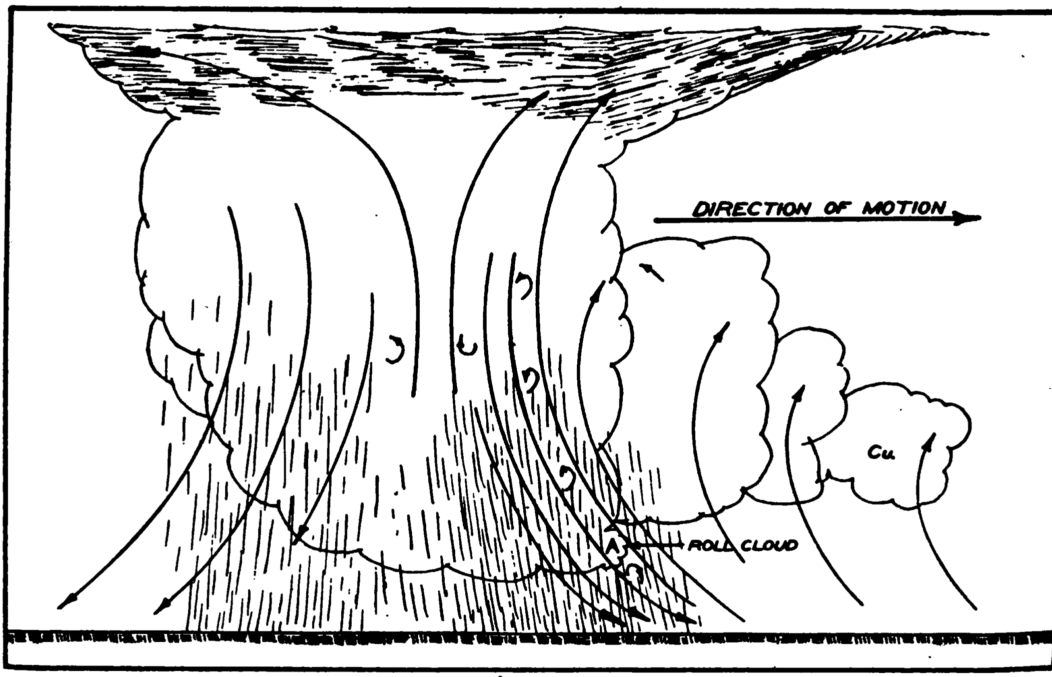


FIGURE 87.—Thunderstorm cloud.

stable layer may not be reached until these currents reach the stratosphere, which explains why these clouds may often extend up to about 35,000 feet.

(3) The direction of motion of the cloud is easy to tell by observing the direction in which the anvil protrudes (see fig. 87). At night, the direction of motion may be determined from some distance by noting the position and movement of the lightning.

(4) Figure 87 also makes clear that the rising currents within the cloud are associated with down currents, both within and without the cloud. Eddy currents result and visible curls are produced which give the cloud a cauliflower appearance, especially in the lower levels. When the cloud reaches a level where the water droplets freeze, the cloud assumes a fibrous appearance. The fact that the cauliflower

appearance is often observed to considerable distances above the zero isotherm indicates that such clouds contain water in liquid form at temperatures well below freezing. This water will be referred to later in connection with the icing of aircraft. For the present, all that should be borne in mind is that this layer of cloud between the zero isotherm and the ice crystal level is extremely dangerous with respect to icing.

b. Turbulence.—(1) Pilots have reported several thousand feet of rise in a thunderstorm with the airplane in a dive. Vertical velocities exceeding 200 mph probably exist in severe storms. The strong up-currents in themselves are not so hazardous, but when they are associated with adjacent downdrafts, exceedingly high velocity gradients are created. Load factors far in excess of the safety factor built into airplanes may be encountered; if so, structural damage will certainly result. Spars have been cracked, ribs broken, fuselages twisted, and safety belts torn loose in thunderstorms.

(2) Violent turbulence renders some flight instruments useless, particularly the turn and flight indicators. The turn indicator may quickly indicate its maximum values, with the pilot having no true knowledge of the rate of turn or de ree of slip or skid. Normal control of the airplane has been rer orted as impossible due to the tremendous forces on the control surfaces.

(3) The region of most severe turbulence is between the descending cold air and the rising warm air in the forward portion of the cloud at altitudes between 10,000 and 20,000 feet where maximum vertical motion is occurring. A roll cloud (A in fig. 87) is sometimes formed at the lower forward edge of the main cloud. Airplanes in this region have been violently rolled beyond control of the pilot.

(4) Severe turbulence also occurs in the rapidly forming clouds just ahead of the main cloud. A thunderstorm persists due to this rapid cloud growth in its forward portion. The descending cold air moves down and forward in a fan shape. This forward moving cold air ahead of the storm forces the warm air aloft. A series of actually new thunderstorms are continually forming in advance of the older ones, often giving the impression of an excessively rapid movement of the original storm (a movement faster than that of the prevailing wind).

(5) In arid regions, the descending cold air may kick up a ring of dust ahead of the thunderstorm. The cooler down currents may attain velocities of 60 to 70 mph in strong gusts as they move along the surface just ahead of the storm.

(6) The turbulence below and slightly in advance of the thunderstorm plus the turbulence beneath the cloud and the resultant lowering of visibility by intense precipitation make flying under a thunderstorm unsafe unless a ceiling of at least 2,000 feet over flat terrain is present.

100. Hail stones.—*a.* Hail stones are definite proof of the existence of thunderstorms in unstable air. The structure of hail stones shows conclusively the existence of large vertical velocities in thunderstorms. The hail stones consist of concentric shells of clear ice and snow which indicate that the hail must have been subjected to successive periods of freezing. This implies that the hail stones oscillated between freezing and nonfreezing levels due to the changes in strength of the vertical currents which have been supporting them. Hail stones vary slightly in density, and the velocities required to support them depend upon this factor. Vertical velocities of approximately 100 mph are required to support hail stones 2 inches in diameter. Picture then the magnitude of upward currents that are necessary to support hail stones 5 inches in diameter which have been observed.

b. Hail stones, in themselves, are a hazard to aircraft. They can cause considerable damage to aircraft, and, in particular, to the fabric.

101. Theory of thunder and lightning.—*a.* The falling velocity of raindrops depends on their size. Raindrops 4 mm in diameter will fall with a velocity of about 8 miles per second. If they grow larger than 4 mm in diameter, they will fall faster than 8 miles per second; however, air resistance prevents a faster terminal velocity. Thus 4 mm in diameter and 8 miles per second are the limits of their growth and falling velocity.

b. If the ascending currents in a cumulo-nimbus cloud exceed 8 miles per second, the largest raindrops will be split up into smaller drops and will be carried upward. The ascending currents in a cumulo-nimbus cloud are not steady; they consist of a succession of gusts and lulls, so that the drops may rise and fall, grow and break up repeatedly.

c. Each time a drop breaks up into smaller drops the negative and positive charges of electricity will be separated, the air taking up a negative charge and the drops a positive charge. By repeated splitting up of drops, an enormous electric charge is set up in the cloud. Since the air ascends much more rapidly than the drops that break up, it follows that the positive charge is accumulated in the

part of the cloud where the ascending current is the strongest and the rest of the cloud becomes negatively charged or neutral.

d. Figure 88 shows diagrammatically the distribution of electric charges in a thundercloud. The positive charge is concentrated in the core of the ascending currents. The rest of the water cloud is usually negatively charged, and the ice cloud carries a positive charge.

e. When there has been a sufficient gradient built up, an abrupt discharge takes place. The destruction of this potential causes lightning, and the accompanying thunder is the same as that caused by

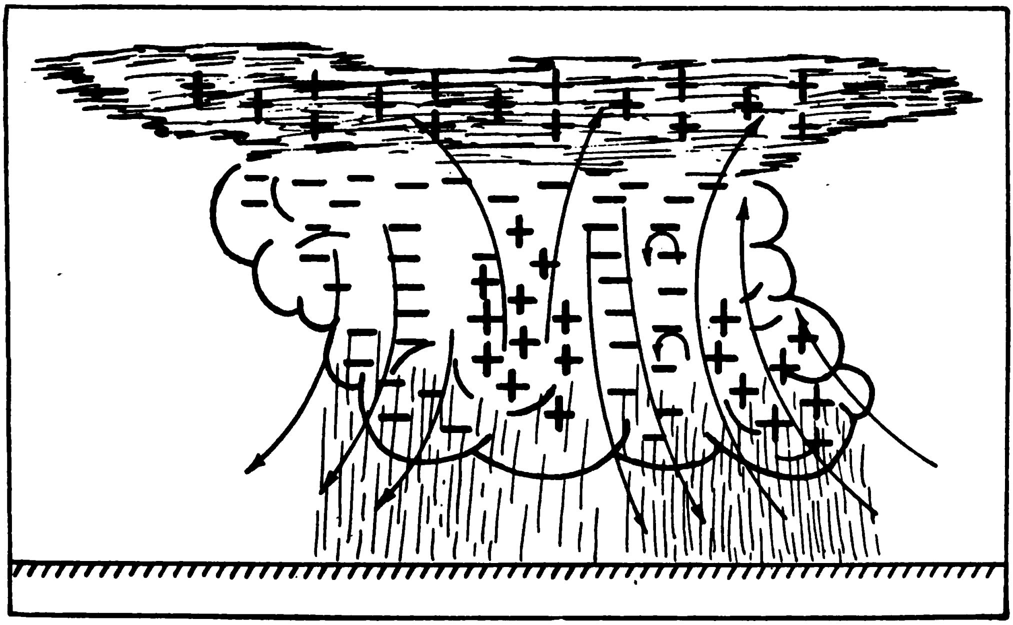


FIGURE 88.—Distribution of electric charge in a thundercloud.

a spark gap. The discharge may go from the positive of a cloud to the negative of the same cloud, from the positive of one cloud to the negative of another cloud, or from the positive of a cloud to the negative of the earth.

f. The details of this theory or of any other (and alternative mechanisms have been suggested) are rather academic to the aviator. The practical fact is that an intense convective system does lead to localized charges of electricity within the cloud mass, enormous electrical tensions are set up, and when these are sufficient the discharge occurs.

g. The strongest lightning discharge may be conducted by a metal rod the size of a man's thumb, so there appears to be little opportunity for serious structural damage to a metal airplane by lightning. However, trailing antennae offer a convenient path for lightning and

several cases have been reported where radio sets have been seriously damaged with some discomfort to the radio operator. Older airplanes of the "stick and wire" type present several points at which lightning may cause damage, one of the most notable of which is at control cable junctions, particularly at the ailerons. Present records show no airplane casualties due to lightning itself.

h. A curious property of the atmosphere, which is only made evident in special circumstances, is the large variation in electrical potential with height. In fine weather this averages about 150 volts per meter; in thundery conditions it may be in the order of 10,000 volts per meter. An aircraft in flight, by friction and through the exhaust gases, rapidly assumes the potential of its environment, but it is quite possible for an appreciable residual charge to persist until an aircraft reaches the ground. Arrangements are therefore made to insure the immediate earthing of the aircraft on landing, so as to avoid the risk of spark and shock to personnel on the ground. In balloons and airships the matter is more serious. The tethered kite-balloon being in electrical contact with the ground is at a potential very different from that of the air at its level and a spark discharge may occur, with the risk of fire. It is worth noting that in the official investigation into the destruction by fire of the German airship Hindenburg in May, 1937, it was concluded that the accident was caused by the ignition of a mixture of hydrogen and air, and the theory that a brush discharge ignited the mixture was regarded as the most probable. The airship caught fire a few minutes after the tail ropes had touched the ground; it was presumed that the airship was electrically earthed and being at a potential different from the air at its level, brush discharge might well have occurred.

102. Mechanics of thunderstorm.—*a. General.*—(1) It should by now be clear in the mind of the student that an intense convective system must exist for a thunderstorm to occur. However, it is unnecessary that the air be totally unstable for a thunderstorm to take place. Only rarely do conditions within the atmosphere attain absolute instability, and then in the lowermost portions only. If the air is conditionally unstable, the vertical velocities necessary in thunderstorms may occur if certain things take place.

(2) Conditional (potential) instability in the atmosphere is the case when the air in the lower layers is resistant to up and down currents (stable), whereas the air aloft is nonresistant (unstable). A closer inspection will verify that conditional instability in the atmosphere is that state in which the air is stable when dry, and unstable when saturated. However, before the air can be saturated, cooling

must take place. Cooling occurs when air rises. Thus, in order to have thunderstorm activity, the air close to the surface must rise and become saturated so that its instability will be released. The problem therefore resolves down to initiating vertical currents in the lower layers.

(3) These vertical currents may be started by one or more of the following:

(*a*) Frontal activity.

(*b*) Topographic influences.

(*c*) Convergence.

(*d*) Heating of the air close to the earth's surface.

b. Thunderstorms due to forced lift.—(1) A front, mountains, or convergent flow of air will initiate upward currents by forcing air aloft.

(2) Just how a thunderstorm can occur by forced lift of air is best explained by means of an adiabatic diagram. In figure 89, the air temperature is plotted from an upper air sounding.

(3) The specific humidity of the air at the surface is 8 (8 grams of water vapor per kilogram of air). At the surface, however, the temperature is 15° C. and the air can hold about 11 grams of water vapor per kilogram of air. This is indicated by the saturated specific humidity line passing through the surface point. In order for this air to become saturated it must be cooled so that 8 grams of water vapor will be all that a kilogram of air can hold.

(4) If this air at the surface were forced aloft, it would cool by expansion, dry adiabatically (3° C. per 1,000 feet). This lifting and cooling process is indicated by following the dry adiabat from the surface point. Note that at about 2,000 feet, this adiabat meets the 8 grams specific humidity line which means that the air has been cooled to saturation (has been cooled to the extent that 8 grams of water vapor is all it can hold). Further cooling caused by further lift will cause condensation of some of this water vapor since at this lower temperature the air will not have the ability to hold all this water vapor. This level then is the condensation level of the surface air. From this level upward the air will cool moist adiabatically (about 1.5° C. per 1,000 feet), and the cloud formed at the condensation level will grow vertically; more condensation continues to take place due to the expansional cooling of the rising air.

(5) As indicated in the diagram, the rising air will be colder than the surrounding air up to the 6,000 foot level (that level at which the moist adiabat crosses the air temperature curve). Therefore, up to this level there is resistance to lifting (no tendency for upward cur-

rents) since the rising air, in being colder, is denser and thus heavier than the air about it.

(6) However, above the 6,000 foot level (level of free convection), the rising air is warmer than the surrounding air all along its ascent. Being warmer, it is less dense and lighter than the air about it. Thus, above 6,000 feet, free convection will take place. Air that has been forced to rise this high would now rise of its own accord, according

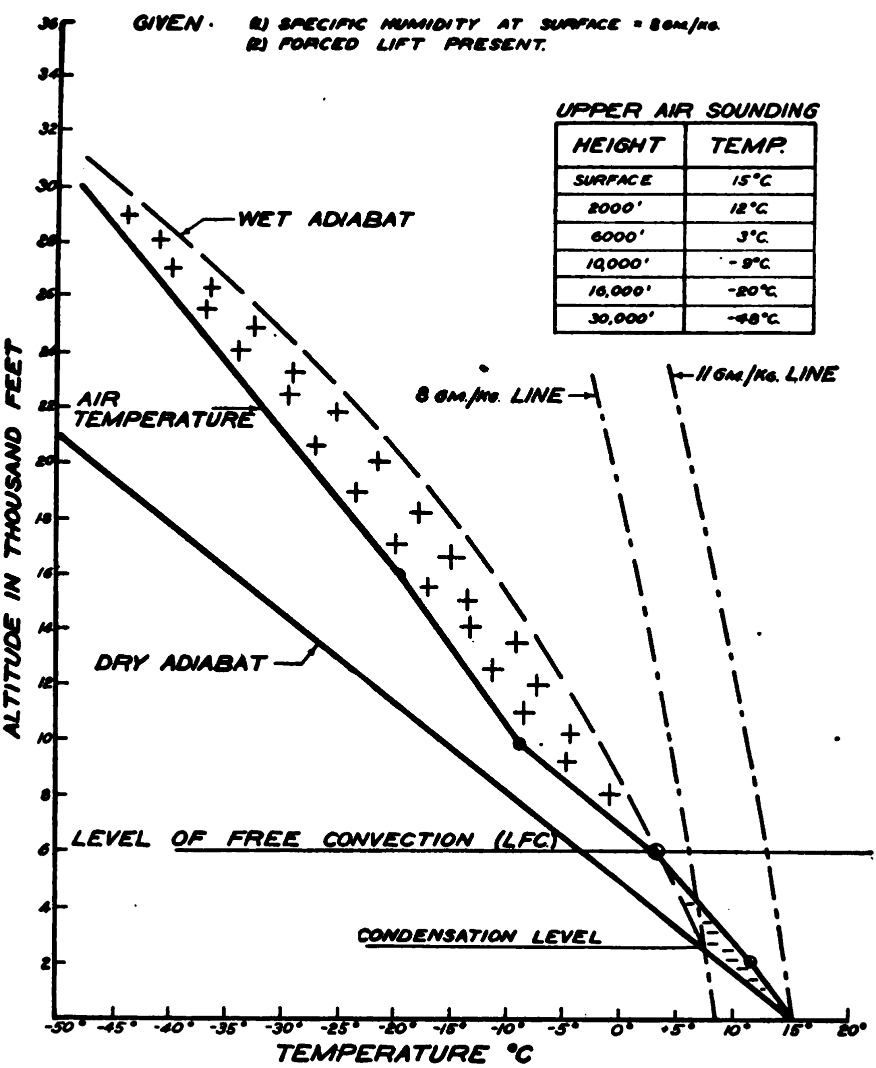


FIGURE 89.—Thunderstorm due to forced lift.

to this particular sounding. Acceleration will take place and the vertical currents will begin to reach the proportions mentioned earlier in this section. As seen in the diagram, the rising air will be warmer than the surrounding air as high as the sounding was taken (30,000 foot level). It will also be noted that these upward currents at this level will have a temperature of about −45° C. In other words, the ice crystal level will have been reached.

(7) In conclusion, if air were forced up to the level of free convection, acceleration of the upward currents would take place. High velocities would occur, great enough to break up raindrops and build up an electrical potential within the cloud, and the cloud would develop vertically to elevations higher than the ice crystal level, which usually exists at about the −15° C. level (18,000 feet in this case). Obviously, the resultant cloud is cumulo-nimbus and a thunderstorm would occur.

(8) This, however, would not take place if some force were not present to lift the air up to the level of free convection since below this level there is resistance to upward currents. Such a force can be supplied by terrain (wind across mountains), by a front (warm air rising over the heavier cold air), and by convergence (west wind $\overset{\uparrow\uparrow}{\rightarrow\leftarrow}$ east wind). A thunderstorm produced in this manner is said to be one produced by forced lift.

(9) Such thunderstorms, therefore, result from lifting conditionally unstable, moist air to its saturation level, from where the air is aided in its upward movement by the instability of the saturated air, particularly after it has reached the level of free convection.

(10) That portion of the diagram where the rising air is colder than the surrounding air is called the negative area, and the size of this area measures the amount of resistance to vertical motion (to thunderstorm activity). That portion of the diagram where the rising air is warmer than the surrounding air is called the positive area, and the size of this area measures the amount of energy available for thunderstorm activity. Whenever the positive area is large and the negative area is small, chances for a thunderstorm to occur are great; however, if the positive area were small and the negative area large, a thunderstorm would hardly occur. These positive and negative areas have no connection whatsoever with electric charges within a thunderstorm cloud.

c. Thunderstorm due to surface heating.—(1) Vertical velocities may also be initiated by convective currents caused from surface heating.

(2) In figure 90, the air temperature represents an upper air sounding obtained during the early morning. A surface inversion is present, typical of a morning sounding. The negative and positive areas are shown. How can a thunderstorm occur with such a favorable sounding if forced lift is not present?

(3) If forced lift were present up to the level of free convection (approximately 10,000 feet), acceleration of the upward currents would take place, high velocities would result, and the cloud would

develop vertically to elevations higher than the ice crystal level. A thunderstorm would occur in the same manner as that in figure 89.

(4) However, in this particular case (fig. 90), no forced lift is present. Below 10,000 feet, as indicated by the negative area, there is resistance to (no tendency for) upward currents since rising air up to the level of free convection is colder than the surrounding air. How

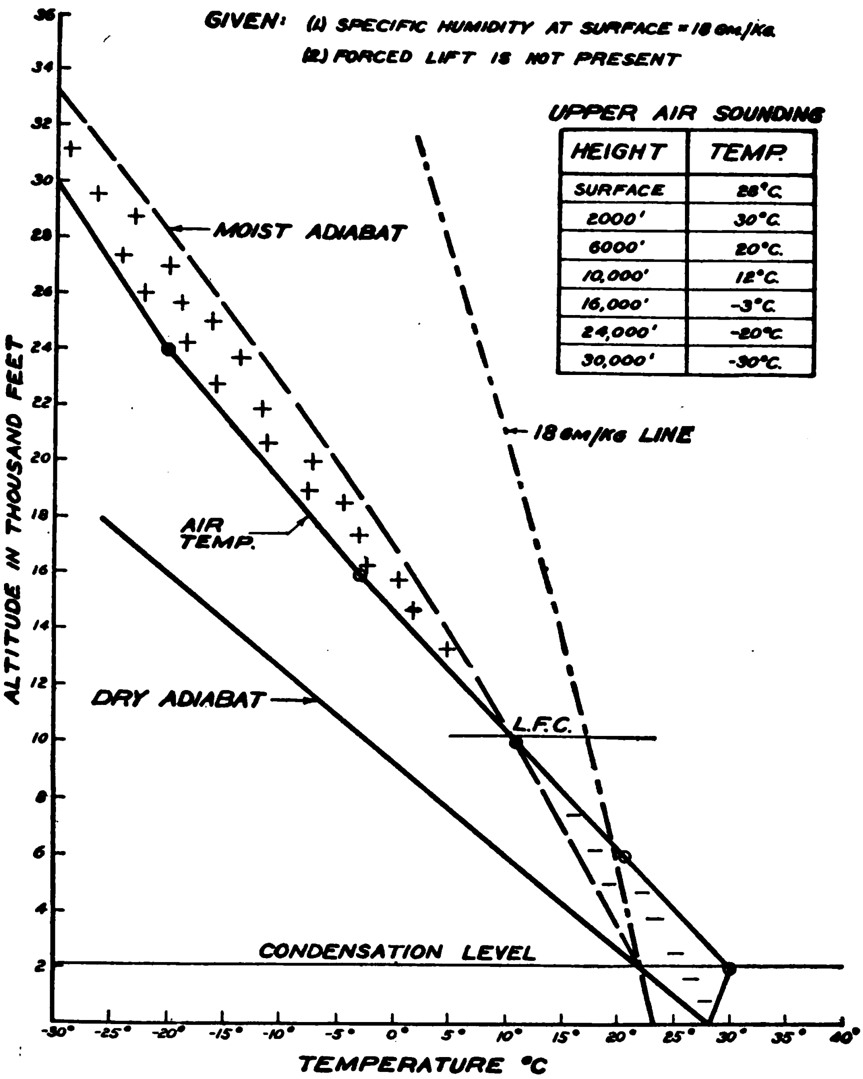


FIGURE 90.—Thunderstorm due to diurnal heating.

then, may this stable layer of air be overcome and a thunderstorm made to occur?

(5) This layer of resistance may be entirely destroyed as indicated in figure 91. Keep in mind that the sounding is one taken in the early hours of the morning.

(6) As heating progresses during the day, several changes will occur in the lower layers of the atmosphere. The upper layers will change

but little. First, the surface will become heated as a result of insolation. By conduction and terrestrial radiation the air in contact with and close to the earth's surface is also heated. Heating of the air at the surface sets up convective currents and mixing of the air takes place which causes all the air in the lower layers to be heated. As a result, the curve in the lower layers swings to the right as indicated in fig-

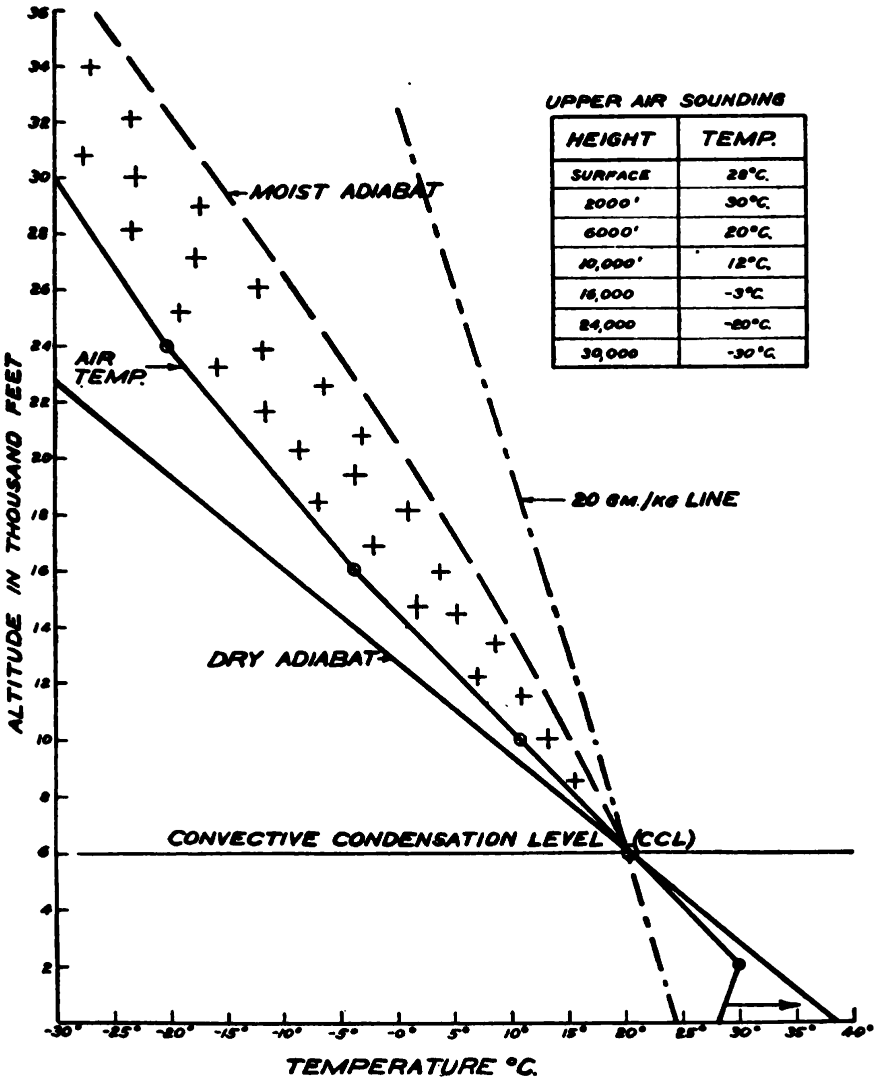


FIGURE 91.—Thunderstorm due to diurnal heating.

ure 91. In other words, the air in the lower layers is tending to become less stable.

(7) Mixing and convective lifting of these lower layers will continue more and more vigorously as the surface continues to be heated during the day. A level will finally be reached when the ascending air columns will be cooled sufficiently to reach saturation. The level at which this occurs is called the convective condensation level. It is

shown in figure 91, and represents the level of the base of the cumulus clouds that will form.

(8) All air movements below the convective condensation level are concerned with the unsaturated or dry state. Air particles in this region, therefore, cool or are heated dry adiabatically. The convective condensation level may be determined from a study of the sounding in the early morning. This level lies at the intersection of the air temperature curve with the saturated specific humidity line, representing the average specific humidity of the lower layers of the atmosphere.

(9) For example, in the morning if the air at 6,000 feet contains 18 grams of water vapor per kilogram, the air at 2,000 feet contains 24, and the air at the surface contains 18, the average specific humidity will be 20. This will be the specific humidity of the air between 6,000 feet and the surface later in the day after vertical mixing has taken place by convective currents. This is so since the water vapor content of the atmosphere will not change unless precipitation is occurring or more vapor is picked up by the atmosphere (passage over water surface). The specific humidity of the atmosphere is a conservative property and is therefore not subject to much change during the day.

(10) These convective currents that are set up cause lifting of the air with resultant dry adiabatic cooling until the 20 gram saturated specific humidity line is reached. The air is now saturated as it has all the water vapor it can hold at this colder temperature (about 20° C.). From here on up the air will rise moist adiabatically.

(11) It is to be noted that the negative area was completely destroyed by diurnal heating of the lower layers (surface temperature increased to 38° C.), and that the positive area was increased in size. There is no level now at which a rising air parcel is colder than the surrounding air. The convective currents will attain the necessary velocities, a cumulo-nimbus cloud will develop, and a thunderstorm will occur if the surface temperature is raised from 28° C. to 38° C. Figure 91 represents the usual relationships existing in an *air mass thunderstorm.*

103. Conditions necessary for thunderstorm activity.—From the previous discussions, the conditions necessary for thunderstorm activity should be clear. They are—

a. Air that is at least conditionally unstable.

b. Moist air to supply the necessary energy to help cause and maintain the storm. Perhaps it would be easier to remember this con-

dition by keeping in mind that such a huge cloud could not be built up without moist air.

c. Some means of lift. There must be forced lift or convective currents to supply the trigger action necessary to release the atmosphere's instability.

d. Vertical currents must reach the ice crystal level. This condition implies that by so doing they attain velocities great enough to split up raindrops and build up a strong electric charge.

104. Classification of thunderstorms.—There are two principal types of thunderstorms each of which may be readily recognized by the synoptic situation:

a. Air mass thunderstorms.

b. Frontal thunderstorms.

105. Air mass thunderstorms.—*a. General.*—(1) Air mass thunderstorms are those which occur well within air masses, unaffected by frontal activity. They are initiated by convective currents caused by heating or by forced lift over mountains. Since surface heating is a prerequisite, they occur in the daytime and usually in the afternoon. They seldom occur above latitude 45° where unstable air and intense surface heating are lacking. In the temperate zone they are common only in summer. They may occur at any time of the year in the Tropics but are much more frequent during the rainy season.

(2) Over a large body of water, air mass thunderstorms are to be expected at night rather than in the daytime due to the decreased stability of the air over water at night.

(3) The increasing instability of the air during the day over land is obvious to a pilot. Surface heating by the sun gives rise to isolated, irregularly spaced convections beginning at the ground which reveal themselves to the pilot early in the day in the form of "bumps." Later, these small convections are strengthened by merging and additional heating until they form a rapidly growing cumulus cloud which may develop into a thunderstorm, usually in the afternoon. Thunderstorms that occur earlier in the day usually have some other cause besides diurnal heating.

(4) The setting of the sun cuts off the primary source of energy for air mass thunderstorms. They then tend to dissipate and disappear. Some of them may attain sufficient strength in the afternoon to persist until late at night.

b. Events at one station.—A fully developed thunderstorm is accompanied by strong gusts, heavy rain or hail, and lightning and

thunder. The wind freshens during the approach of the storm, blowing at first toward the advancing storm. As the thundercloud arrives overhead, the wind changes in direction, blowing out from the storm in a forward direction. The barometer falls while the storm approaches, but when the wind changes a brisk rise amounting to a few millibars occurs. The precipitation, commencing as a sudden heavy downpour, changes into a more continuous rain which gradually decreases in intensity.

c. Flight plan in air mass thunderstorm area.—(1) Over a large area, air mass thunderstorms are scattered. They should present no serious hazard to the pilot since it is possible for him to avoid the individual storms by circumnavigation.

(2) Just why air mass thunderstorms are isolated is easily explained by figure 87. Once a thunderstorm is started, it aids convections ahead of it and depresses those to the sides and rear. As a result, each storm becomes isolated. Convections in advance of the cloud are aided by the downward rushing cold air which is forcing warm, moist air aloft. Thus, rapid cloud growth takes place in the forward portion. However, the air along the sides and rear is relatively cold and dry as it has already been used up by the storm as it was approaching. Convections here are therefore depressed since descending currents in these regions mix with colder, drier air which increases the stability and the height of the saturation level of the air. The ceiling may rapidly rise from a few hundred feet in the forward portion to several thousand feet in the ragged clouds that are continually disappearing at the rear of the storm.

(3) Obviously, such storms should offer no big problem to the pilot since by simply flying around them, they can be avoided.

d. Terrain and convergence.—(1) Terrain and convergence can by themselves supply the lift necessary to initiate thunderstorm activity. However, diurnal heating is usually found cooperating in conjunction with these factors.

(2) Over mountains, convections are rapidly set up and thunderstorms occur very easily. The air around a mountain which is not snow-covered is heated faster than the surrounding air, convective currents are set up. Tropical islands, especially those with mountains, cause thunderstorms due to convections set up on a hot day. The resulting showers may be very intense, due to the large amount of water in the air.

(3) The normal trajectory of Tg air (mT air from the Gulf of Mexico) in summer is onshore from the Gulf of Mexico. When this air rises over the increased land elevations, especially in west Texas,

the lift required for saturation gradually decreases except for a short distance onshore. By the time the air has reached ground elevations of 2,000 or 3,000 feet the formation of a thunderstorm is quite probable, and a little added lift will cause them. This small added lift may be due to further progress up the gentle slope or by convections set up by diurnal heating.

(4) Maritime tropical air from the Gulf of Mexico (Tg) is the only North American air mass which is normally sufficiently unstable for the saturated state to produce thunderstorms. At least 90 percent of all thunderstorms that occur in the United States occur in this mT air. Their maximum frequency occurs near the Gulf of Mexico in the afternoon. Over the Gulf of Mexico their maximum frequency is at night.

(5) Due to Tg air, the mountains in west Texas, New Mexico, Colorado, Arizona, California, Utah, and sometimes even Oregon, Washington, Idaho, Montana, and Wyoming and the Ozark and Appalachian Mountains cause many thunderstorms.

(6) Convergence plays an active part in maintaining thunderstorms and in initiating thunderstorm activity along the Atlantic Coast. If the wind is westerly (and it very often is, due to the prevailing westerlies), convergence will be set up in the summer along the Atlantic Coast due to the sea breeze. The front edge of the sea breeze aids materially in the formation of cumulus clouds which sometimes develop into cumulo-nimbus. These thunderstorms occur more frequently several miles inland since the sea breeze attains its maximum value during the hottest portion of the day. Here, as in mountainous terrain, diurnal heating also aids, but this time in two ways: by establishing the sea breeze resulting in convergence, and by establishing convective currents.

106. Frontal thunderstorms.—*a. General.*—(1) Frontal thunderstorms occur as a result of vertical motions created by a front. The relatively warm air of one air mass is forced to rise over the relatively cold air of the other air mass.

(2) The chief difference between air mass and frontal thunderstorms is the manner in which vertical currents are initiated. In air mass thunderstorms, surface heating by the sun makes the air in the lower layers unstable, resulting in the necessary vertical currents. In frontal thunderstorms, the potentially unstable warm air is forced over the cold air (frontal surface acting like a mountain) to its level of free convection whereupon the instability of this air is released and vertical currents occur. In a discussion of frontal thunderstorms the factors affecting air mass thunderstorms must be kept in mind.

(3) Frontal thunderstorms may not be diminished greatly by nightfall, and they may originate and persist during the night. The origin and occurrence of thunderstorms at night are an excellent indication to the pilot that he is in a region of frontal activity. Another important indication is the distribution of thunderstorms. When they occur in a more or less continuous line or in close proximity, the pilot may be reasonably sure that they exist in or near a frontal zone.

b. Warm front thunderstorms.—(1) If the warm air is stable, as indicated by the air temperature in figure 92, the forced lift of warm air over the cold air will produce a stratified layer of clouds; this is true, because at no level in the forced ascent of the warm air is there a tendency for upward currents. In such a case, there will

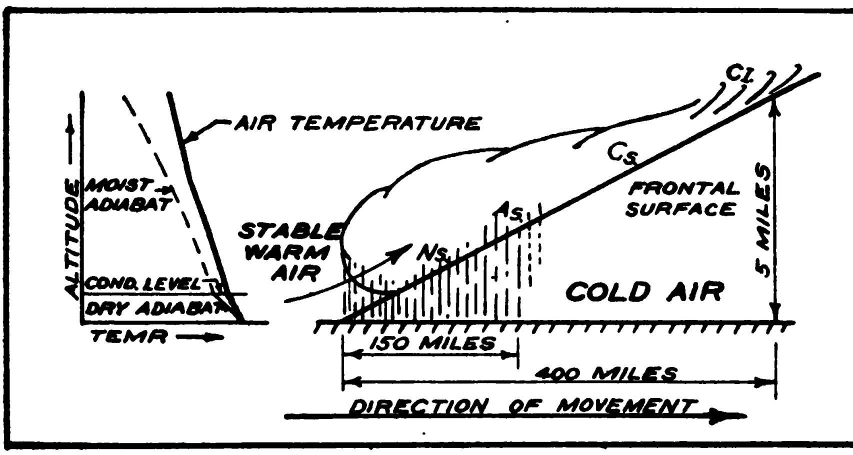


FIGURE 92.—Warm front (stable warm air).

be no thunderstorm activity, but just precipitation from the nimbostratus and alto-stratus clouds; smooth, rather than rough flying; and any icing will probably be of the rime type.

(2) However, if the warm air is conditionally unstable, just as the air was in figure 89, the instability of this potentially unstable air is released when it is forced over the cold air up to the level of free convection. Upward currents will be set up, cumulo-nimbus clouds will develop, and probably result in thunderstorm activity.

(3) Now, besides a stratified system of clouds, there will also be cumulo-nimbus clouds which develop in the alto-stratus clouds over the cold air. These thunderstorm clouds rise above the alto-stratus layer and reach the level of the cirrus clouds. In figure 93 a section of a map showing a warm front, and the precipitation area associated with it is shown; a vertical cross section along the line AB is also pictured.

(4) Note that the pilot should occasionally fly over the alto-stratus layer to see what might be lurking ahead in the overcast. He will

then be able to avoid the individual scattered thunderstorms by flying between and around them. However, the situation is still precarious. Such flight would have to be conducted at altitudes around 10,000 feet or higher. Oxygen equipment would probably be essential, especially for a long trip.

(5) Superimposed upon the steady precipitation from the stratiform clouds will be the intense precipitation from the thunderstorm clouds. This makes the warm front precipitation spotty, as is indicated in the diagram. Such intense precipitation, thunder and lightning are clues

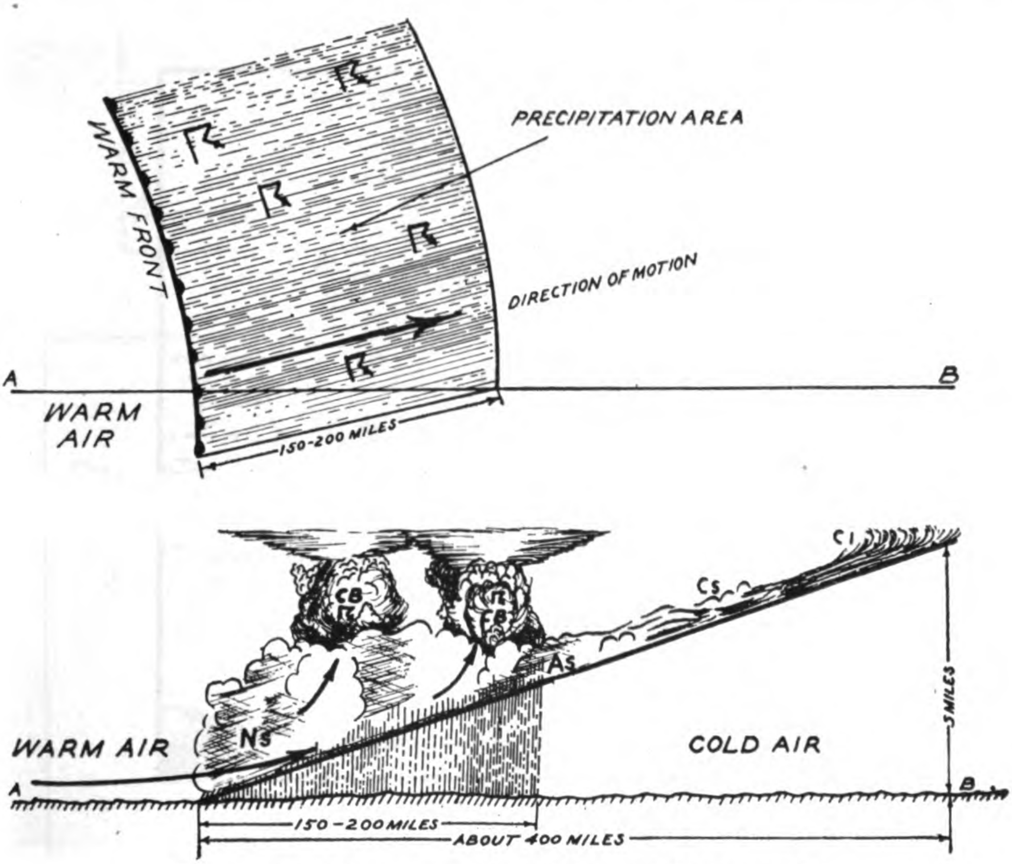


FIGURE 93.—Warm front (potentially unstable warm air).

that very turbulent weather exists in the warm front clouds. The precipitation from the thunderstorm also combines with the warm front precipitation to raise the relative humidity in the cold air, thereby decreasing the ceilings and enhancing the possibilities for fog in advance of the warm front at the surface. It should be clear that the possible zero ceilings and visibilities make low flying in advance of a warm front extremely dangerous and inadvisable.

(6) Any icing would probably be a combination of rime and the more dangerous type, clear ice.

c. Cold front thunderstorms.—(1) If the warm air is stable, flying weather similar to that in connection with the warm front pictured in figure 92 would be expected. However, the stratiform cloud deck would probably cover a smaller area. It would appear somewhat in advance of the surface front and extend up over the frontal surface. The clouds would be thicker vertically, although they might be concentrated in a narrower band along the surface front, a band 50 to 100 miles wide but extending hundreds of miles along the front. Precipitation would be of the continuous type, moderate to heavy. Thunderstorms would not be present.

FIGURE 94.—Knucklehead still has not learned.

(2) The proper way to fly through this type of cloud system would be straight through. This is shown in figure 64. However, the pilot should be on the alert, realizing the possibility of encountering thunderstorms.

(3) If the warm air is potentially unstable, cumulo-nimbus clouds rising over the alto-stratus deck might be expected. This is shown in figure 96.

(4) The essential difference between this weather and that associated with a warm front with potentially unstable warm air (fig. 93), is again one of concentration. The cold front thunderstorms would be encountered along, or in advance of, the surface front. Flying

through such a cold front would involve the same precautions as were discussed for figure 93.

(5) The situation is very different, however, if the cold front is a fast moving or strong front. In figure 97, a section of a map showing

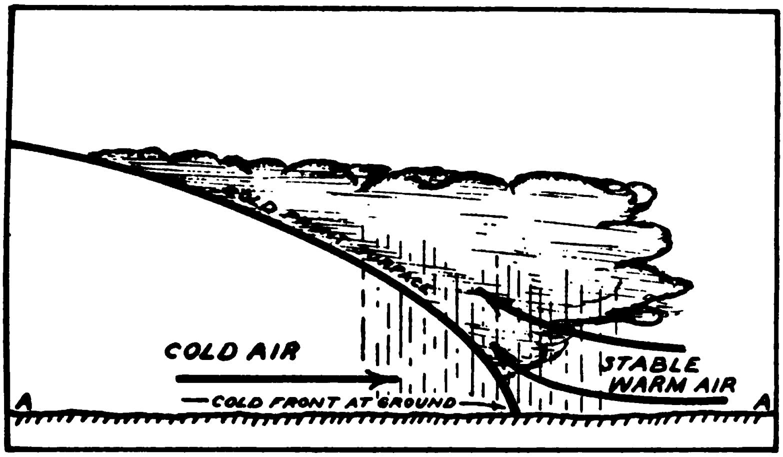


FIGURE 95.—Cold front (stable warm air).

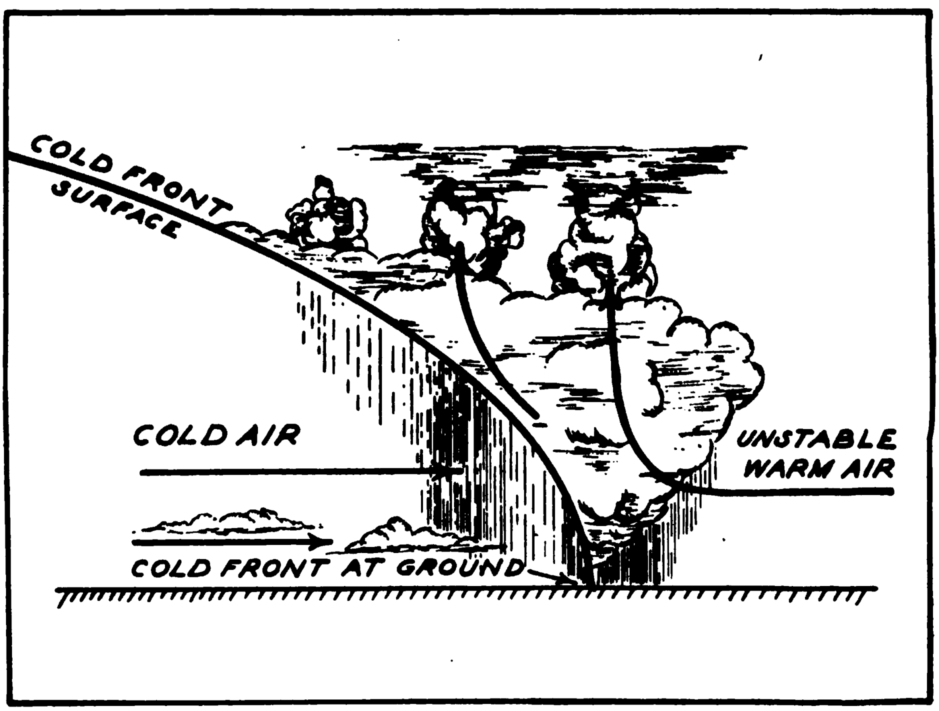


FIGURE 96.—Cold front (potentially unstable warm air).

a strong cold front and the precipitation area associated with it is shown; a vertical cross section taken along the line AB is also pictured.

(6) Because of the unusual steepness of such a cold front, the warm, conditionally unstable air receives its maximum lift suddenly along, or in advance of, the line of the surface front.

(7) The extreme steepness of this front, which causes a bulge, is due to the friction of the earth's surface. The faster the front is moving, the greater is the effect of the friction and the steeper the front will be, since the front at the surface is retarded by friction whereas the front aloft is not.

(8) Along such a strong or fast moving cold front the most severe type of thunderstorm is encountered. The front may result in a continuous line of thunderstorms; that is, an almost solid wall of

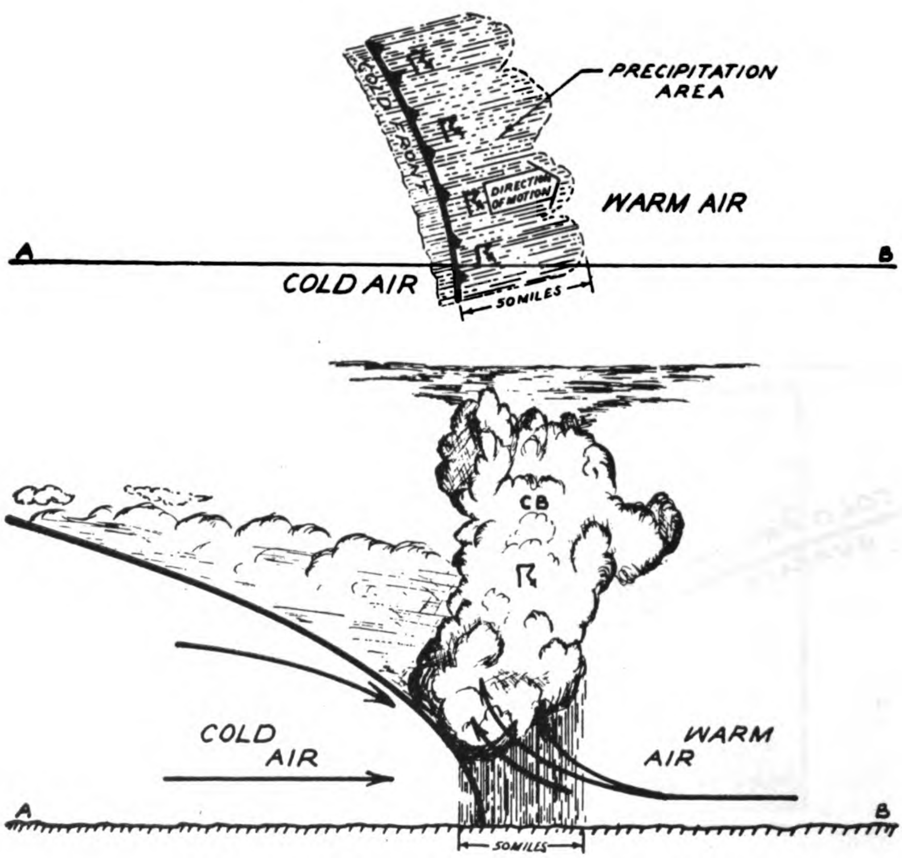


FIGURE 97.—Fast moving cold front with a squall line.

cumulo-nimbus clouds, about 50 miles thick, perhaps 35,000 feet high, and extending the length of the cold front. Such a continuous line of thunderstorm clouds along a strong cold front is known as a squall line.

(9) The turbulence in a squall line thunderstorm is most severe. Expert instrument pilots who have flown into a squall line have been forced to turn back because they could not control their airplanes. One pilot related his experiences briefly, "I went in at 12,000 feet and it spit me out at 18,000." A large percentage of all aircraft weather accidents occur along a strong cold front.

(10) The best flight plan with such a situation is to wait until the front passes and then take off. Obviously, flight over the clouds is impossible unless oxygen equipment is available. Flight through such a cloud is forbidden in peace time because of the severe turbulence plus the added dangers of clear ice and hail stones. Flight below the cloud is also extremely dangerous due to the severe gustiness, zero visibility in the heavy precipitation, and possible low ceiling.

(11) When it is absolutely necessary to fly through a squall line, it is perhaps best to fly parallel to the squall line clouds, look for a clear space at least 1 mile wide and then fly through the opening. This is pictured in figure 98.

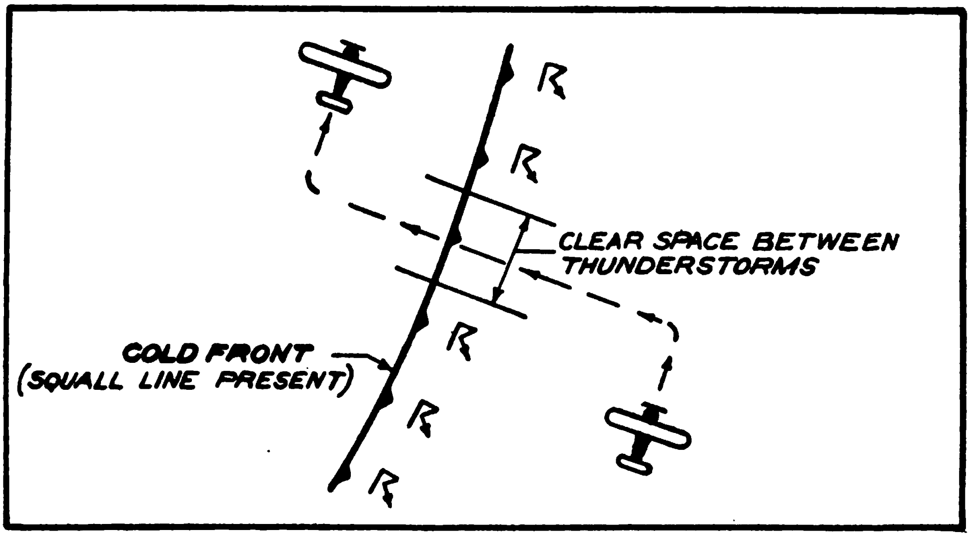


FIGURE 98.—Flight path through squall line.

107. Comments on thunderstorms by airline pilots.—The following general experiences by airline pilots may be of interest to some of those who have not had much experience with thunderstorms.

a. "Have heard a few pilots and co-pilots make the statement that they have never seen a thunderstorm so rough that they could not fly instruments in them. Would like to suggest that I do not think they have seen them all yet, but if they keep on looking they will probably find at least one."

b. "While flying blind in overcast in the vicinity of Sunbury, Pennsylvania, at 10,000 feet we hit a down draft and fell 4,000 feet absolutely out of control. I think we were inverted more or less—anyway, the gyro compass and horizon went out like a candle in a tornado. At about 6,000 feet we regained control for about 15 seconds or so and then hit another draft almost as violent as the first. We re-

gained control from this one about 3,000 and, as the hills in that vicinity are about 2,000 feet, we decided that the passengers would be more comfortable on a train and we proceeded to land at Sunbury. There was no squall line and this storm must have been of the over-running type as there was a solid overcast about 3,000 feet above sea level. Another trip that preceded us only 45 minutes experienced only moderately rough air. This occurred at about 6:00 PM, June, 1933."

c. "Late this Spring left CX on morning trip. CX 200 ft., 3 miles, light rain, temp. 62. wind WNW10. After taking off we pulled into overcast, climbing gradually. About 10 minutes out we encountered severe lightning flashes. The overcast began to get darker, the temperature dropped 15 degrees in 10 seconds. Shortly, we ran into a severe hail storm and also a down draft, which slowed us down to 70 mph, losing about 2,000 feet per minute although the ship was at a steep climbing angle in low pitch. During the storm the ship was almost completely out of control. Being blind and caught unawares is rather disconcerting at times, especially over mountainous country. Study of the late map did show a slight wind shift."

d. "On one occasion upon entering front edge of a line squall I was able to idle motors and climb 3,000 feet at about 1,000 feet per minute. The ascent was smooth and even."

e. "Was caught in a very severe line squall in Texas and came out of the top tail first at about 14,000 feet. I ran into the storm at about 6,000 feet. Had absolutely no control of the ship and was almost ready to bail out. How long do you suppose I would have been up in a parachute?"

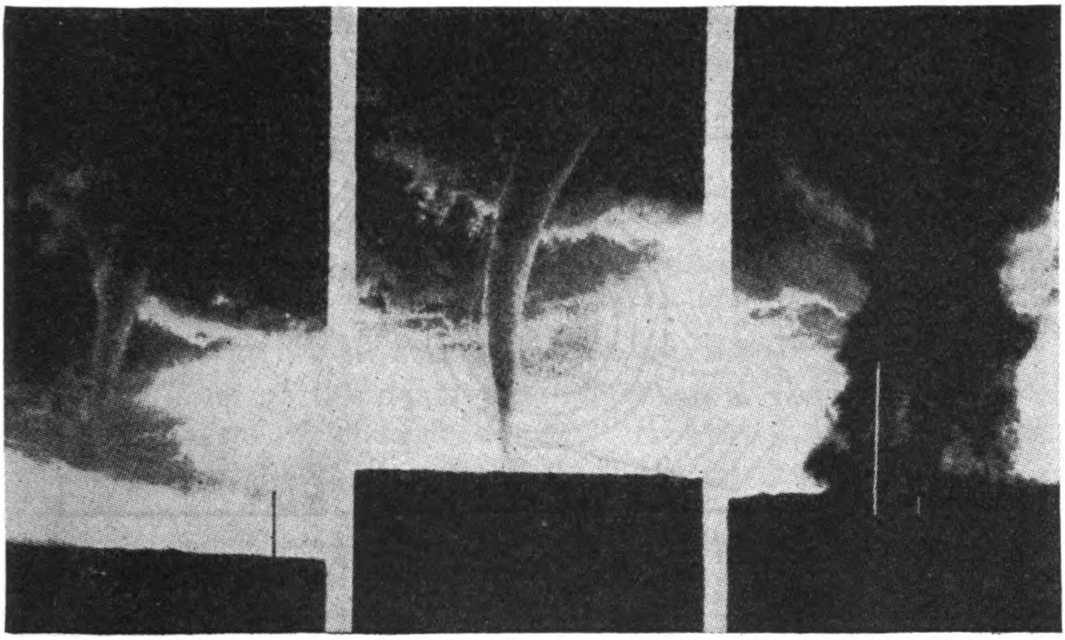
108. Tornadoes.—A tornado is a very violent storm of small extent with intense cyclonic rotation accompanied by heavy rain, usually lightning, and frequently hail. Tornadoes are distinguished from hurricanes by their extent and continuance. They are usually only a few hundred yards in diameter and their track on the ground less than 25 miles in length. In the United States they occur most frequently in the central portion of the Middle West but they have been reported from every State in the Union. Because of their short extent, they do not appear on a weather map and forecasting them is so difficult that most forecasters refrain from the practice.

a. Causes.—Tornadoes result from extreme instability and are almost invariably associated with severe thunderstorms. Most of the tornadoes in the United States occur in the late spring and early summer, with a secondary maximum in the fall. They usually occur

along or a short distance in advance of a cold surface front between mP and Tg air. Tornadoes have been observed to occur entirely within one air mass but always in connection with thunderstorm activity. They apparently grow out of the roll cloud as it bends down toward the earth. This probably accounts for the close relation between tornadoes and thunderstorms.

b. *Movements.*—(1) Tornadoes build down from above.

(2) They may strike the surface at one point and then skip some distance before they reach the surface again.



① Tornado cone forming. ② Fully developed cone as it reaches the earth. ③ Tornado striking farm-house, which appears to explode.

FIGURE 99.

(3) They move with the prevailing wind. The movement of the front may create new tornadoes, giving a false impression of individual motion. Whether a tornado builds down to the surface or whether it apparently skips along depends largely upon the relation between the winds aloft and the surface winds. Strong winds aloft with light surface winds will cause the upper portion of the tornado to be carried ahead and may lift the tornado from the ground or destroy it completely. Winds aloft of about the same velocity as those near the ground will cause tornadoes of longest duration and intensity. The same factors which help or hinder convections in thunderstorms similarly affect tornadoes.

(4) Winds in a tornado vortex may exceed 500 mph and the centrifugal force in a tornado causes a large reduction of pressure in the center of the whirl. Houses in the path of a tornado may seem to explode. Dust and debris are picked up by the suction effect giving the tornado the appearance of a black, sinuous cone extending from the ground up to the base of the clouds. The appearance is so typical and the extent so small that in daytime the path may be avoided without difficulty. Since, like thunderstorms, they move with the prevailing winds, the path of an observed tornado may be roughly forecasted. A pilot should never get caught in a tornado except possibly at night and even then the accompanying lightning should give a good clue as to its location.

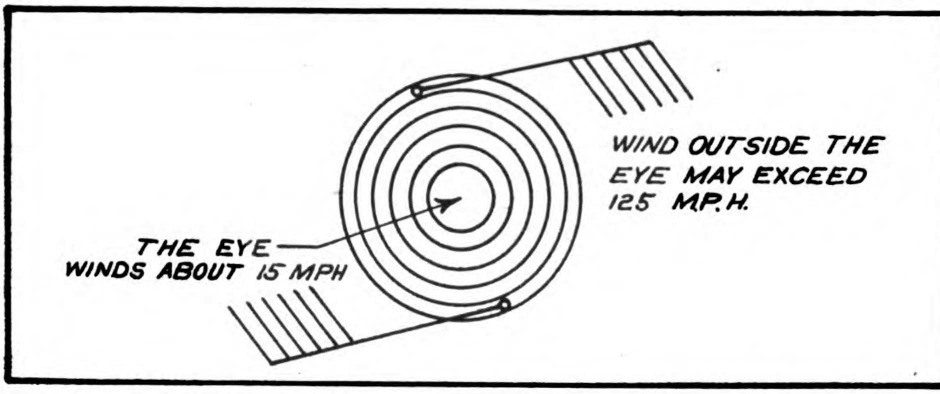


FIGURE 100.—Hurricane, as it would appear on a weather map.

109. Hurricanes.—*a.* A hurricane is an unusually violent cyclone of tropical origin. In the East Indies and China seas a hurricane is known as a typhoon.

b. The origin of hurricanes has not yet been definitely established. Many hurricanes have been found to occur along old polar fronts that have been carried into tropical latitudes. Assuming an established wave, the energy released by the heavy precipitation is so great that the young cyclone rapidly progresses until almost complete occlusion has taken place. Circular isobars about the center are the result, as pictured in figure 100.

c. A hurricane differs from a tornado in many respects but chiefly in its extent. A hurricane usually has a diameter of 300 to 500 miles. There is a relatively calm area at the center, 15 to 30 miles wide, known as the eye. In the eye, the winds are about 15 mph and the sky may be clear. Outward from the eye the wind velocities are very high as indicated by the close spacing of the isobars. The winds

may have velocities exceeding 125 mph. From the air, the first signs of a hurricane are the cirrus clouds and swells on the sea. Clouds become denser as the eye is approached. Ceilings and visibilities come down, torrential rainfall, thunderstorms and sometimes hail take place.

d. The hurricane maintains itself by the energy it picks up in the form of water vapor from the tropical sea or ocean. Movement over land quickly destroys the intensity of the hurricane.

e. Hurricanes travel with a speed of about 20 to 40 mph. Their easy recognition makes it inexcusable for a pilot to be caught in one and this is especially true since their rate of movement is very slow as compared to airplane speed.

QUESTIONS

1. When flying in the vicinity of thunderstorms, what should the pilot do?
2. What cloud is associated with thunderstorms? Give a brief description.
3. Briefly, why are air mass thunderstorms usually scattered?
4. Give some of the dangers associated with severe turbulence.
5. Where is the region of most severe turbulence in a thunderstorm?
6. What is the stability of the air in which thunderstorms may occur?
7. Give the means by which vertical currents may be initiated.
8. Define the level of free convection, convergence, and diurnal heating.
9. How does diurnal heating affect thunderstorm activity?
10. Give the conditions necessary for thunderstorm activity.
11. What are the two general types of thunderstorms? Differentiate between them.
12. How should the pilot fly in an air mass thunderstorm area?
13. During what time of the day are air mass thunderstorms most likely to occur? Frontal thunderstorms?
14. What should be the flight plan through a squall line?
15. What is the most severe type of thunderstorm the pilot can encounter?
16. Where are warm front thunderstorms located?

SECTION XIII

ICING

110. General.—*a.* Until instrument flying came into general use several years ago very little was known about icing on aircraft. With the increase of blind flight through clouds, icing became one of the major problems confronting pilots and weather forecasters during the winter season.

b. Icing is known to rank along with thunderstorms and fog as one of the three major weather hazards with which an airman has to contend. In a series of wind tunnel experiments it was shown that ½ inch of ice deposited at the 5 percent position on a 100-inch airfoil reduced the lift about 50 percent, increased the drag by an equal amount and greatly increased the stalling speed. Applied to a BT-9, the stalling speed would increase 20 mph. A very serious condition further arises in that a pilot has no means of determining whether or not a critical condition is arising and the stalling speed is being approached.

c. A number of examples are on record where 2 or 3 inches have been deposited on aircraft in as many minutes. During the winter of 1940, a United Air Lines pilot reported having accumulated 5 inches of ice in 3 minutes near El Paso, Texas. It is important, therefore, that pilots should be well informed on this danger, and should know the best ways to cope with it to fly safely and with dispatch.

111. Kinds of ice.—*a. Frost.*—Frost is a thin deposit of ice crystals formed by sublimation. It forms most frequently when the plane is left outside the hangar at night, and is not serious except that it increases drag and therefore reduces lift and the aerodynamic efficiency of the plane. It should be wiped off or otherwise removed from the plane before taking off. Frost is also deposited on the aircraft when it comes down out of a subzero stratum of air into warm moist air below. Bombers diving from cold air above to warm moist air below

would experience this type of icing. It melts or evaporates as the plane warms up in the warmer air below and ceases to give trouble. When it is deposited on the windshield it cuts visibility and makes landing difficult. Canadian Air Lines frequently meet with this kind of frost deposit in landing at Vancouver, after coming down from the high levels flown in order to clear the Rockies.

b. Rime ice.—(1) Rime is a granular, whitish, opaque, and rough deposit of ice from tiny supercooled water drops found in the stratiform clouds of stable air. It has been found at temperatures ranging from −28° C. to −2° C. Only 36 percent of the cases of rime ice reported were found above −8° C.

(2) The tiny drops encountered in the stratus type clouds do not spread over the airfoil as do large ones, but freeze at once and freeze separately into tiny ice pellet form. This instantaneous and separate freezing results in air pockets and a mechanically weak deposit of rime ice. Rime has, therefore, little adhesion for the plane or cohesion for itself. It is readily removed from the plane by vibration and wind action, although rivets, skin laps, and localized rough surfaces become anchorages for rime.

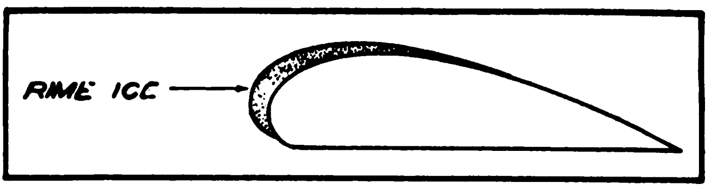


FIGURE 101.—Rime ice on an airfoil.

(3) Figure 101 shows that since these tiny drops do not spread out, but freeze immediately upon contact with the plane, the resultant rime deposit does not seriously deform the shape of the airfoil, nor seriously modify its flight characteristics. Rime is not generally considered serious as a flight hazard.

(4) The conditions necessary for rime ice formation are:

(*a*) Visible water.

(*b*) Tiny liquid drops.

(*c*) Subfreezing temperatures, −28° C. to −2° C.

(*d*) Stable air.

(*e*) Stratiform clouds.

c. Clear ice (glaze).—(1) This is clear, smooth, amorphous ice. In unstable air vertical turbulent currents build cumuliform clouds. In their formation large supercooled rain drops develop. When a plane encounters these supercooled drops they freeze quickly into a tenacious glaze which is dangerous and difficult to deal with. Supercooling is

not unusual: liquid water is often found at temperatures as low as −30° C.; clear ice has been known to form as low as −22° C.

(2) The large drops encountered in cumuliform clouds and in rain do not freeze instantaneously and separately. Instead they spread out while freezing, and before being entirely frozen other drops merge upon them and likewise spread outward while freezing. This continuous process eliminates air pockets and results in a mechanically strong deposit of clear ice. It sticks tenaciously and since it is formed from large drops, it accumulates very rapidly. As figure 102 indicates, large drops form a mushroom like deposit of clear ice, which seriously modifies the aerodynamic characteristics of an airfoil. Clear ice is recognized as the worst type of ice hazard encountered in flying.

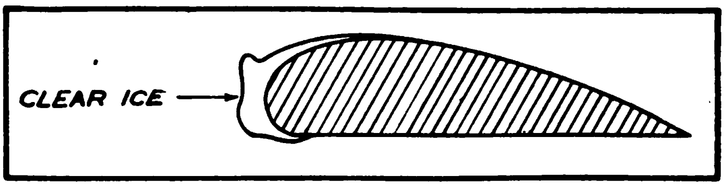


FIGURE 102.—Clear ice on an airfoil.

(3) The conditions necessary for clear ice formation are:

(*a*) Visible water.

(*b*) Large liquid drops.

(*c*) Subfreezing temperatures, −22° C. to 0° C.

(*d*) Unstable air.

(*e*) Cumuliform clouds.

d. Combination of rime and clear ice.—(1) From the fact that both clear and rime ice are found at temperatures between −22° C. and −2° C., one would expect both of these types of ice to be found on an airfoil which has been through clouds associated with certain systems. Clouds may contain:

(*a*) Fog particles, diameter 10 to 70 microns.

(*b*) Mist particles, diameter 70 to 500 microns.

(*c*) Raindrops, diameter 500 to 4000 microns.

(2) One notes there are drops of extreme differences in size. This condition will be found in the upslope stratified cloud system above a warm front which normally is composed of fog and mist particles. If this air is potentially unstable mT air, it will reach the level of free convection. Energy will then be released to form a series of cumuliform clouds with their characteristic large drops of liquid water. These will be superimposed upon the stratified clouds already present. A plane flying through such a cloud system would intercept both large and small drops producing a mixture of clear and rime ice.

(3) Furthermore, if the plane were flying through such a cloud system at a temperature −5° C., all of the fog particles and the smaller mist particles would form rime ice while the larger mist and all the raindrops frozen would be spread out and form clear ice. If the clouds were at a temperature of −15° C. or −20° C., all the fog and mist particles and some of the smaller raindrops would freeze into rime and only the larger raindrops would be frozen into clear ice.

(4) Rime ice forms 3 or 4 times more often than clear ice.

112. Icing hazards.—*a. Propeller ice.*—Ice deposited on the propeller may upset the aerodynamic efficiency, produce dynamic unbalance and fracture the airfoil structure when thrown off by centrifugal force. Pieces of ice thrown off are unequal in size. The dynamic unbalance produced when 1 pound of ice is thrown from a propeller blade of a BT-9 at a distance of 4 feet from the hub, when cruising speed is 1850 rpm, would be 4,700 pounds. This is almost enough force, as one pilot put it, "to tear the engine out of the plane".

b. Carburetor ice.—Ice can readily form in the throat of the carburetor due to the cooling effect of the reduced pressure produced by the Venturi flow of air through its constricted parts and the cooling effect of the rapid evaporation of gasoline into the air stream. Carburetor ice modifies the mixture of gas and air and seriously reduces the power of the engine. Heating devices are installed so that air will be admitted to the carburetor at about 100° F. giving a resultant temperature of about 35° F. to the gas and air mixture. Extreme care should be taken in warming up of the engine that carburetor ice does not form and retard the free flow of gas when maximum power is needed for take-off. Serious accidents at take-off have been reported due to engine and power failure from this cause.

c. Tail surfaces.—The deposit of ice in its various forms on the tail surfaces of the plane may affect the longitudinal and directional control.

113. Ice annoyances.—*a. Windshield ice.*—Ice becomes an annoyance to the pilot when deposited on the windshield, reducing visibility. It is particularly dangerous when present at time of landing. Ice will form simultaneously on the lens in front of the landing lights, adding to the difficulty of safe landing at night. Windshield ice is shown in figure 103.

b. Pitot tube ice.—Ice in the pitot tube reduces its size and changes the flow of air in and around it, making useless or unreliable the air speed instrument. The tube is heated electrically to remove this danger.

c. Snow.—Snow sometimes clogs the oil radiators and the inside of the engine cowl, producing excessively high temperatures. Mechanical devices have been designed to reduce these annoyances to a minimum.

114. Ice formation.—*a. Theory of ice formation.*—This theory in brief is as follows: Supercooled water drops, in striking the plane, are spread out along the airfoil and are furnished the necessary impetus for molecular alignment necessary for crystal formation. Immediately a small amount of the drop freezes and the liberated heat of fusion raises the balance of the drop to zero (0° C.). Evaporation

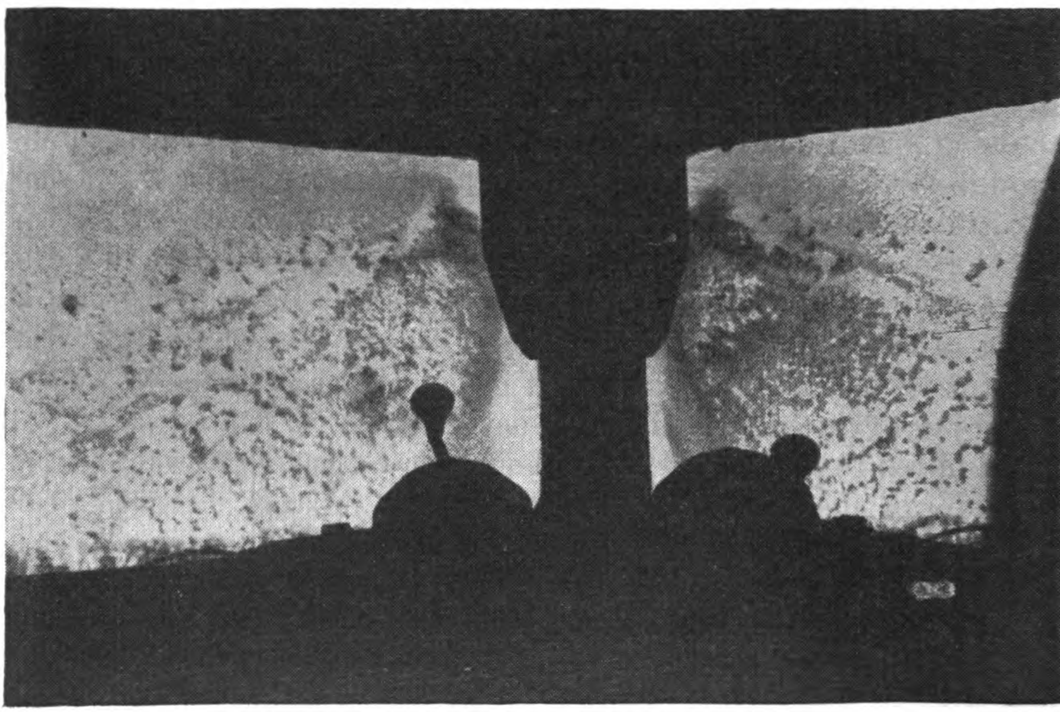


FIGURE 103.—Rime ice on windshield. Picture taken during flight.

of a small amount of the remaining drop furnishes the cooling required to freeze all that is left. If the initial temperature of the supercooled water is −8° C., then about 12 percent of the drop evaporates and 88 percent freezes into ice. Greater percentages of ice will form if the initial temperature of the water is lower.

b. Icing time.—The above is on the assumption that the heat evolved from the freezing of the ice is carried away by evaporation. There is some evidence to show that twice as much is lost by conduction from the plane as by evaporation, and this could account for still larger percentages freezing. However, many aircraft have apparently come through clouds with supercooled large drops with little icing. This

has been explained as follows: that the icing time is directly proportional to the radius of the drops. For large drops, this time may be large enough to permit the drops to coalesce and be blown off the plane in large quantities, carrying away much of the ice formed on the first impact. There is no reason to believe that all the ice formed attaches itself tenaciously to the airfoils upon their encounter.

c. Icing at 0° C.—Ice can be formed at temperatures above freezing only when liquid water is present at a relative humidity of less than 100 percent, which permits some evaporation and the necessary cooling for ice formation. There is also an adiabatic cooling of the air as it flows over the low pressure regions of stream flow over the airfoil. Some investigators are of the opinion that there is sufficient heating of the plane due to friction to make ice formation above 0° C. an impossibility.

115. Air speed and critical icing temperatures.—One needs only to rub his hands together vigorously to experience the heating effect of friction. Metallic meteorites are heated to incandescence by the friction they encounter in the atmosphere at elevations where the density of the air is only $\frac{1}{1000}$ part of that found at flying levels. The friction of the air on an airplane is sufficient to raise the temperature of both the plane and its thermometer a few degrees, depending upon the speed of the plane. This has the effect of raising the zero-temperature flying level of the airplane. At 100 mph this level is 350 feet higher, at 200 mph, 1,500 feet higher, and at 300 mph, 3,400 feet higher than the 0° C. temperature of the free atmosphere. This principle permits the pilot to fly at slightly lower real air temperatures without danger of icing. He should watch carefully his own air temperature thermometer and fly at levels where it records 1° or 2° above zero, the amount depending upon his own air speed. In terms of real air temperatures, this could be as low as −5° C. Frictional heating is reported to be 40 percent lower inside a cloud than outside of it at the same air speed.

116. Synoptic conditions favorable to icing.—These can be classified under two general headings:

a. Under a frontal inversion.—(1) When warm moist mT air is forced to rise over a colder air mass, a frontal inversion will exist, below which icing dangers are frequently encountered. In being forced aloft, sufficient cooling may be experienced to produce saturation and precipitation. The rain drops falling into the cold air may freeze upon contact with the airplane if the temperature is at or below freezing. This dangerous area in the cold air is shown in figure 104.

(2) The cloud system above the front may be stratified or cumuliform. The drops may be small or large and the icing may be rime or clear ice, or both. Often the clear ice is mixed with sleet and snow. A pilot finding himself in an icing zone under such an inversion should climb to the warm air above. A study of aerographic sheets for nearby stations with the necessary extrapolation would give the elevation of the front for any particular position along the route.

b. Where liquid water (fog, cloud, mist, or rain) is found at subfreezing temperatures.—(1) *In stratiform clouds.*—(*a*) Stratified clouds are always indicative of stable air. In them will be found either tiny fog particles, small drops of mist and rain, or ice crystals. If ice crystals, they offer no icing problems since they do not stick to

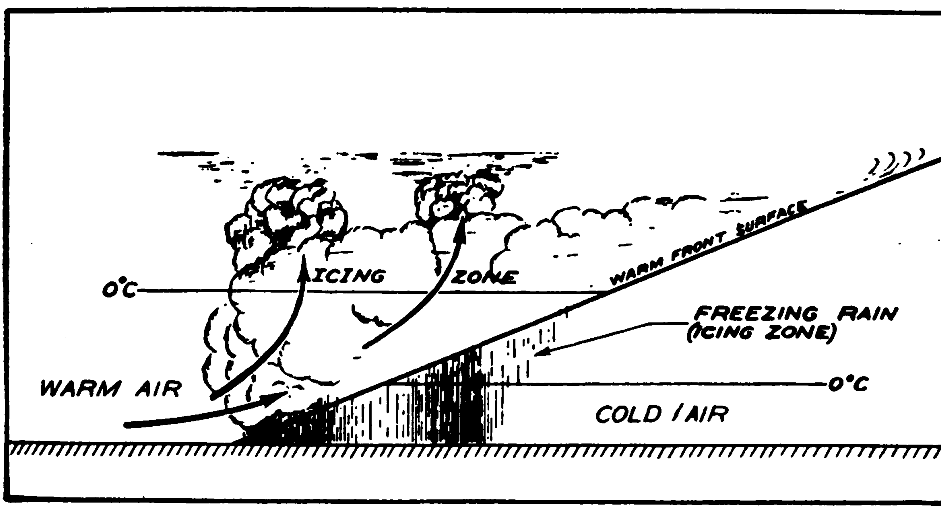


FIGURE 104.—Icing under a front.

the airplane upon impact. The supercooled liquid water in the form of fog or mist will be frozen immediately into rime ice upon contact with the plane.

(*b*) Clear ice may form in the rain zones of these clouds and often rime and clear ice form together. The temperature range can be from 0° C. to −28° C. The vibration of the plane cracks the rime into small chips which are blown away. Flight should be either under these zones where the temperature is above freezing, or above them, where there is no liquid water. The following table gives the relationship between the rate of ice formation, the drop size, and the number of drops per cubic centimeter, when the cloud contains a maximum amount of liquid water, 5 grams per cubic meter, and when it contains an average amount of liquid water, 0.5 grams per cubic meter.

TABLE VI

Drop radius in microns	Depth of ice observed on leading edge of airfoil in inches per minute for liquid content of—		Number drops per cubic centimeter of liquid content of—	
	5.0 grams per cubic meter	0.5 grams per cubic meter	5.0 grams per cubic meter	0.5 grams per cubic meter
3.1	1/32	nil	40, 000	4, 000
6.2	3/16	1/64	5, 000	500
9.3	5/16	1/32	1, 480	148
12.4	3/8	1/32	620	62
15.5	1/2	1/16	340	34
18.6	------------	1/16	190	19

(*c*) From this table it is noted that for a given drop size the rate of deposit is proportional to the liquid water present and that the rate of deposit for a given liquid content is proportional to the size of the drop for this range of fog particles.

(2) *In cumuliform clouds.*—(*a*) Cumuliform clouds are products of unstable air. mT air which is potentially unstable contains great quantities of water vapor. It may be lifted by surface heating or by frontal and orographic influences to the level of free convection where its great energy is released for further vertical development.

(*b*) When the temperature in cumuliform clouds is reduced below the 0° value, icing dangers exist. The vigorous vertical turbulence is able to support relatively large liquid drops which can remain liquid to −22° C. Upon impact with the plane, these large drops spread out, forming clear ice which sticks tenaciously to the plane. Since it can accumulate very rapidly, it becomes a great hazard to flying. Flight should never be attempted through such zones.

(3) *Along warm fronts.*—(*a*) The stratified cloud system associated with the up-glide of warm, moist air over a warm front often reaches dangerous sub-zero temperatures where rime icing will occur. If the warm air mass is potentially unstable, there may arise cumuliform clouds which develop conditions favorable to the formation of clear ice or a combination of clear and rime ice.

(*b*) Figure 105 shows a typical warm front structure with the most probable icing zones and a possible flight path to avoid icing. The cloud system of a warm front is very extensive, necessitating long flights through them with increasing icing dangers.

(4) *Along cold fronts.*—(*a*) Cumuliform clouds are often associated with cold fronts. Clear ice would, therefore, be expected in the

icing zones associated with them. The cloud systems are relatively narrow as compared with those of the warm front and the time required to fly through them is comparatively short. However, due

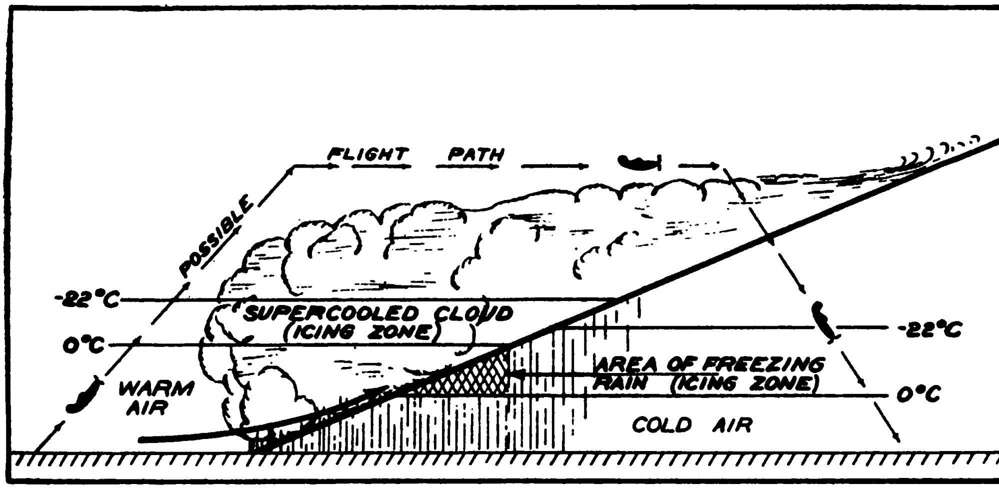


FIGURE 105.—Icing zones along warm front.

to the heavy precipitation, icing can be fast and extremely dangerous, even though short of duration. A possible flight path to avoid icing through the cloud system of a cold front is given in figure 106.

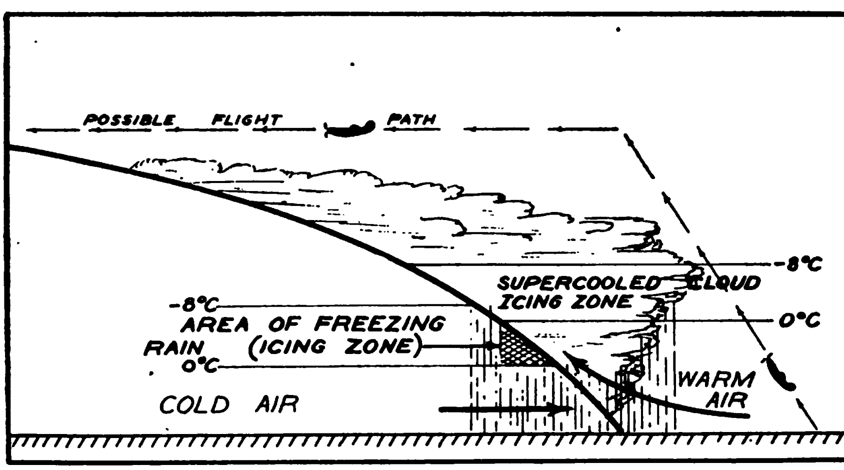


FIGURE 106.—Icing zones along cold front.

(*b*) About 85 percent of the observed icing of aircraft in the United States is associated with frontal systems.

(5) *Over mountains.*—(*a*) The lifting of potentially unstable air over mountain ranges is one of the most serious ice producing processes experienced in the United States. mT air, moving northward and eastward over the Appalachian Mountains, is often cooled to

sub-zero temperatures and becomes an icing hazard to all air traffic that must travel through this air. Similarly, mP air in winter, approaching the west coast of the United States, contains much moisture in its lower levels. As it is forced aloft by the successive mountain ranges encountered in its eastward movement, severe icing zones develop.

(*b*) Figure 107 is a section across parallel ridges showing regions of severe icing. It is noted that these icing zones appear some distance above the crest of the mountains and may continue to considerable heights.

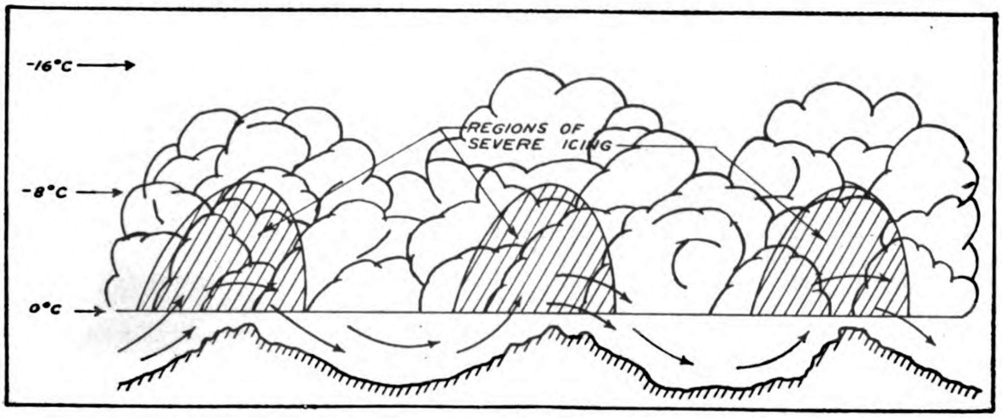


FIGURE 107.—Icing over mountains.

117. De-icers.—A number of techniques have been tried in an effort to eliminate the ice that accumulates on an airfoil. A word may be said about the three most practical methods.

a. Chemical.—This process depends upon the spreading of oil or some other surface coating which will furnish a nonadhesive surface or lower the freezing point of water. Except on propellers, where centripetal action furnishes the spreading force, this method has not yet proved practical.

b. Thermal.—Hot exhaust gases are adequate to keep the surfaces above freezing temperatures if they could be properly diverted and brought into contact with the icing surfaces. This has not been done with satisfaction as yet.

c. Mechanical.—(1) The rubber de-icers are the best of accepted types. They are inflatable rubber tubes attached to the leading edges of the airfoils, automatically inflated to a pressure of 7 pounds per square inch and deflated again in a period of about 9 seconds. Because of their effect on the aerodynamic characteristics of the airfoil they should never be used while taking off and landing.

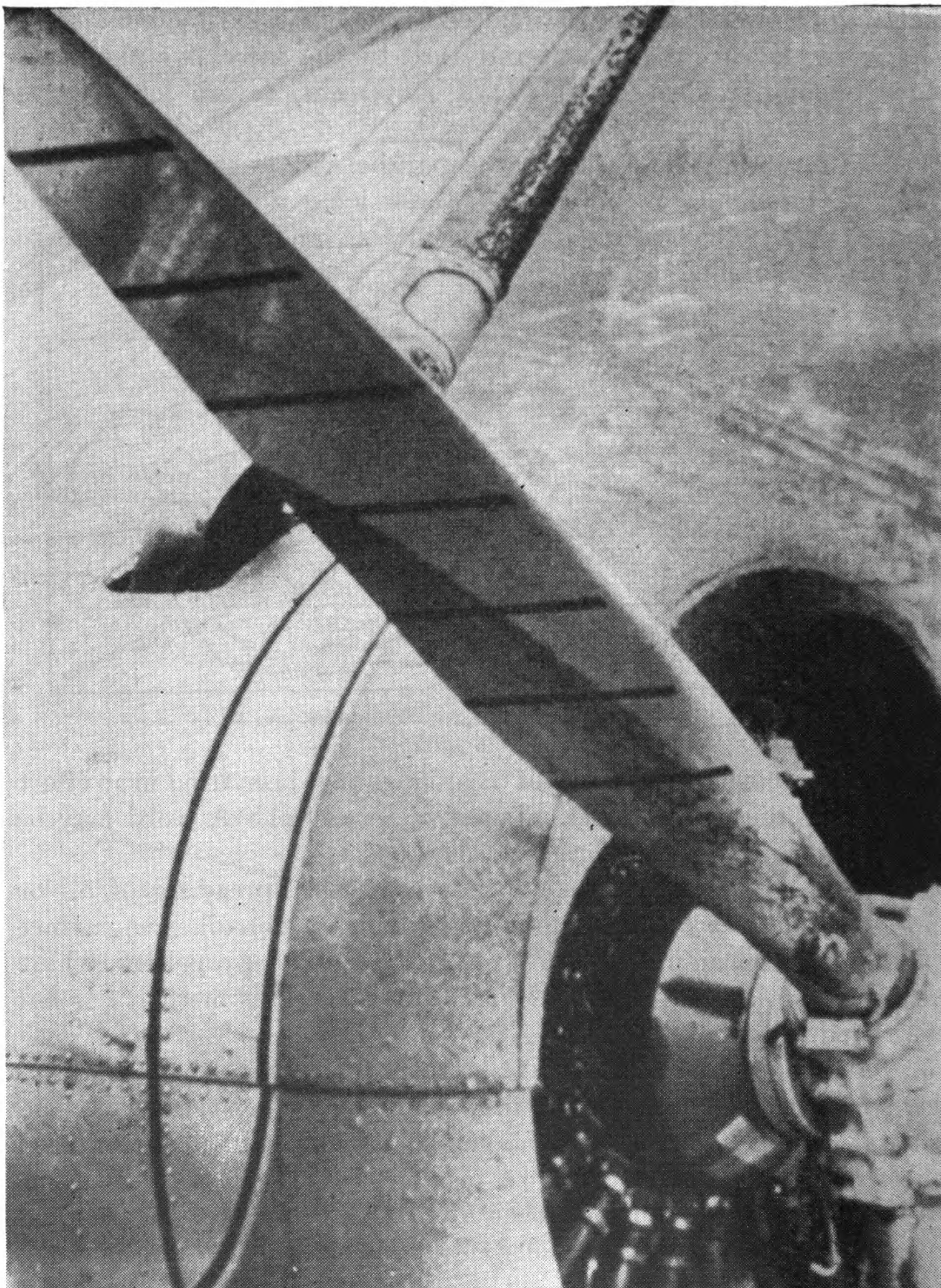


FIGURE 108.—Icing on wing tip.

(2) Some experienced pilots think they should be used intermittently rather than continuously for greater efficiency. A deposit of ice is allowed to form and then cracked off by inflating the de-icers.

Figure 108 illustrates the condition developed in one instance when de-icer operation was continuous through a region where glaze ice was being accumulated. This was only a light icing condition but the ice was forming at such a rate that between each successive tube inflation only a thin coating of ice was added to the de-icer. Upon inflation this thin coating, rather than being blown clear, was crazed into many small patches of ice which remained on the rubber surface and served as anchorage points for further building of ice on them as bases. Successive inflations produced the same patterns in crazing the accumulating ice with the result that many individual projections formed to present the roughened de-icer surface covering the wing's leading edge. The smoothness of the coating of glaze ice over the landing light gives an indication as to the evenness of the adhering ice for portions of the wing not equipped with deicer shoes. The procedure adopted as a result of such happenings has been purposely to avoid operating the de-icers until an ice thickness of approximately ⅛ inch is attained. They are then operated for a short period, sufficient to crack loose this thicker formation so that it is blown from the wing in sizeable sheets. The de-icers are then turned off until the ice thickness again approximates ⅛ inch. Intermittent ice removal in this manner is continued until the region is passed.

(3) At night, the intermittent procedure cannot be easily followed due to the inability of pilots to observe satisfactorily the progress of ice formation.

118. Pilot's recognition of icing.—A pilot may recognize the slow or rapid accumulation of ice on his plane by:

a. Observation on antenna and struts on biplane.

b. Observation along the wings.

c. By logy, unresponsive controls.

d. By sudden foreign vibration.

e. By inability of the plane to climb.

f. By loss of altitude.

g. By loss of air speed.

119. Pilot's precautions.—Severe icing conditions may arise very suddenly, and when they do, the pilot should have at his disposal every agency and technique available. He should—

a. Reduce speed.

b. Get out of the danger regions.

c. In going through an icing strata known to exist, he should do so with maximum rate of climb or descent commensurate with maximum safety.

d. Have available all weather aids such as—

(1) Weather maps, with forecasts and indicated icing zones.

(2) Adiabatic charts of upper air sounding for stations nearest path of flight.

(3) Ground temperatures, dew point, and elevation of flight.

(4) Types of clouds and their icing characteristics.

(5) Have radio contact with nearby stations.

(6) Sometimes fly above the cloud and sometimes below, but in all cases stay out of icing zones.

FIGURE 109.—Knucklehead gets his wings.

120. Summary.—*a.* Icing conditions may be expected in any form of cloud where the temperature is below 0° C.

b. Icing hazard above clouds is not great.

c. Icing may occur in rain below a cloud if the lower cold air has cooled the aircraft to 0° C. or lower.

d. Clear ice will predominate at temperatures from 0° C. to −8° C.

e. Clear ice may be expected in clouds with appropriate temperatures where vertical currents can support larger drops. These conditions may be realized when the following are present:

(1) Convective action from surface heating.

(2) Vertical convection force by cold fronts.

(3) Active upglide of warm air over the warm front.

(4) Orographic lifting.

(5) Those conditions shown on an adiabatic diagram as being within a layer of unstable air.

f. Rime will predominate at temperatures below $-8°$ C.

g. Rime will be expected in stratus clouds where vertical currents are of insufficient strength to support larger drops.

h. The adiabatic diagram will indicate stable conditions within the zone of rime formation.

i. Ice clouds furnish no hazard since the ice crystals will not adhere to the plane.

j. Icing is severe in frontal zones.

k. Icing is severe in upslope conditions over mountains and fronts.

121. Icing elevations.—The following table is taken from paper Icing Problems Attendant to the Operation of Transport Aircraft, by R. L. McBrien of United Air Lines.

TABLE VII.—*Lowest altitude above sea level at which ice was reported 1936–1940*

Month	Average of lowest altitude reported (feet)	Lowest altitude reported (feet)
October	9, 500	6, 000
November	7, 000	1, 600
December	7, 500	3, 000
January	6, 700	600 (surface)
February	8, 100	3, 000
March	8, 900	4, 500
April	11, 700	6, 000
May	12, 000	12, 000

QUESTIONS

1. Define frost, rime ice, and clear ice.
2. What are the necessary conditions for the formation of rime ice? Clear ice?
3. How can the pilot prevent the formation of carburetor ice? Pitot tube ice?
4. What are the critical temperatures for clear ice formation? Rime ice formation?
5. List the more important effects of icing on an aircraft.
6. Discuss briefly frontal icing.
7. What are the three most practical methods of deicing?

8. Is icing a hazard above the clouds? Give reasons for your answer.

9. What should the pilot do when he encounters icing conditions?

SECTION XIV

WORLD WEATHER

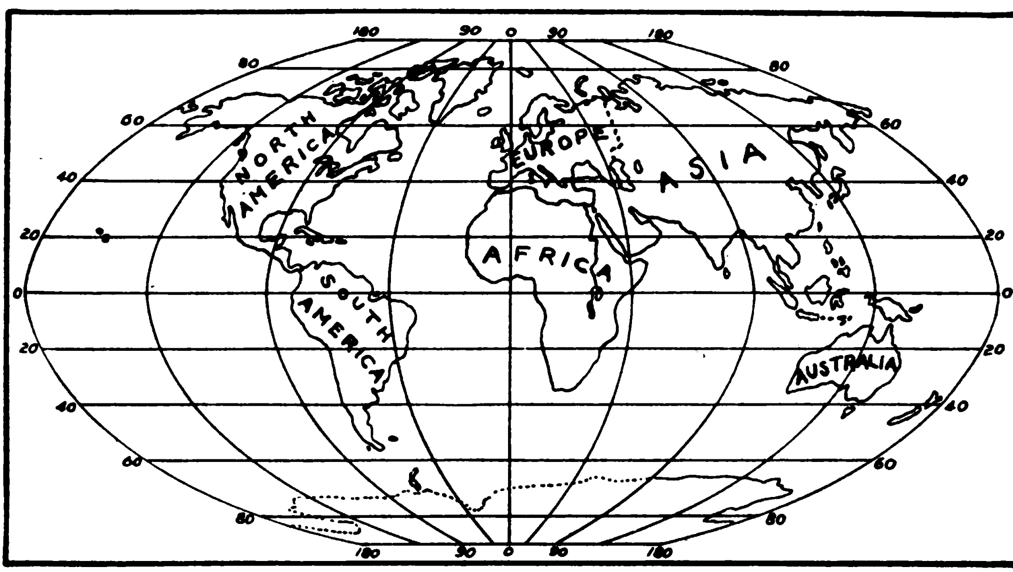


FIGURE 110.—Continents.

122. General.—*a.* If you have learned well each lesson of the weather course in basic flying school you will readily understand the weather conditions as they occur in any part of the world. By way of summarizing the course we shall consider the climate of the various regions and special weather conditions in local areas.

b. Climate may be defined as the sum total of meteorological phenomena that characterize the average state of the atmosphere at any given locality. Weather is a phase—a single act of this succession of phenomena. Climate is a long range view on weather.

c. It is well to keep in mind the fact that places situated in different continents, in the same latitude, at the same altitude, and in corresponding location with respect to the continental mass, generally have the same climatic characteristics. For instance, if you are ordered to western Europe, by comparison with our western coast, you could get a fairly accurate idea of the weather you would find at your new post. The marine influence modifies temperature in both places. Humidity is high and cloudiness is excessive. Frontal activity moves over both coasts. However, there are other factors which may locally upset the generalized picture. Such variations will be discussed as each region is considered.

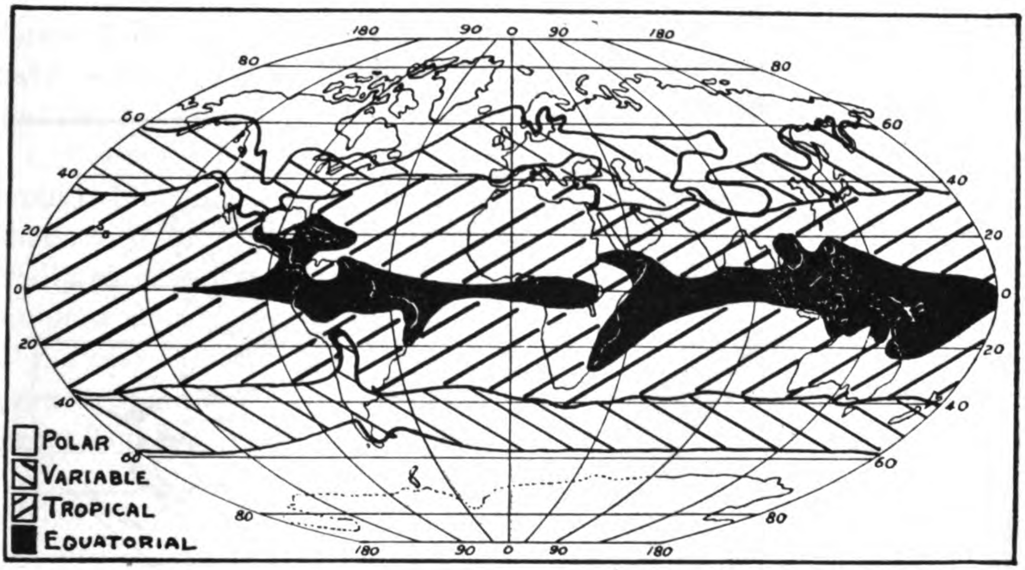


FIGURE 111.—Climate.

123. Climatic regions.—*a.* The four major climates result from the general circulation of the atmosphere which in turn is caused primarily by intense solar insolation near the equator and the rotation of the earth.

b. Intense heating in equatorial areas expands the air and all layers are lifted. Ascending motion is characteristic of equatorial regions. Contraction of air over cold polar areas lowers all layers, hence there is descending motion over polar regions. In general, therefore, surface winds tend to move equatorward and upper air tends to move poleward.

c. Rotation of the earth deflects poleward moving winds to the east and equatorward moving winds to the west. A belt of high pressure tends to build and maintain itself along the Tropics. Here the air is descending, compressing lower layers and warming them, hence the

warm dry tropical and subtropical belt with its extensive desert areas.

d. Air moving from the cold polar regions meets air moving out on the poleward side of the "tropical highs" giving us another belt which we shall term variable region because of the frequent changes as first one then the other air mass dominates.

QUESTIONS

1. Why is the name "variable" especially applicable to the climate in middle latitudes? Give reasons for the conditions found there.

2. Why are west coasts at 50° latitude wetter and warmer than east coasts at the same latitude?

3. Name and locate six tropical desert regions.

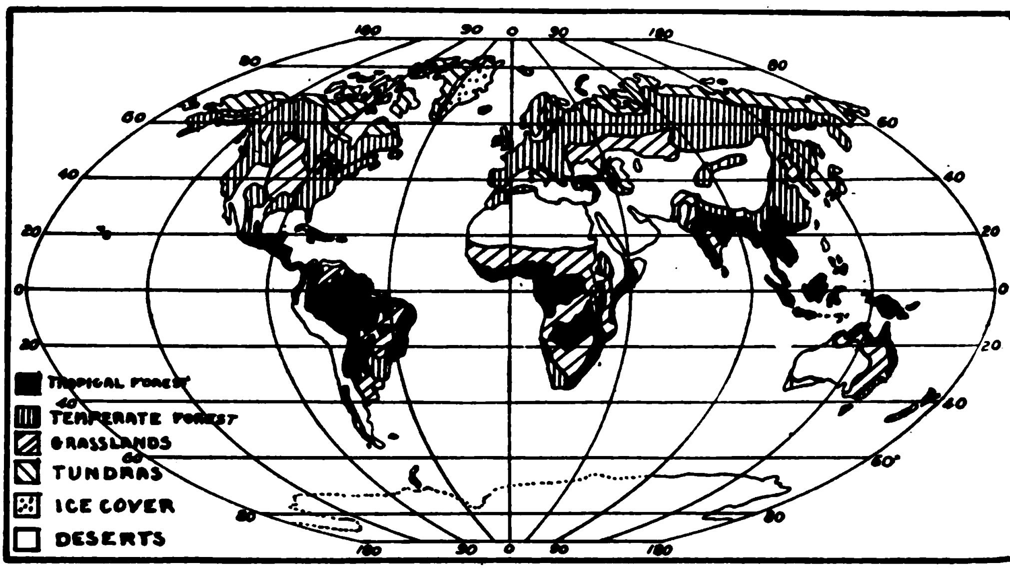


FIGURE 112.—Vegetation.

124. Vegetation.—*a.* The presence of forests, grasses or desert shrubs reflect climatic conditions. Forests in low latitudes grow where temperature is always hot and precipitation heavy. In these areas, precipitation resulting from rising unstable moist air will be of the showery type largely from isolated cumulo-nimbus clouds. Such clouds are frequent during the afternoons over land surfaces and may be avoided. Flying weather is generally good at night and during the morning hours over equatorial forests. Dense growth makes safe forced landings practically impossible except on water bodies in or near the forests.

b. Deserts on or near the tropics are conspicuous by their lack of vegetative cover. Warm lands without precipitation, and with light

winds blowing out of high pressure areas extend across all large continental masses. Flying weather over tropical deserts is nearly ideal except for an occasional dust or sand storm.

c. Between tropical deserts and equatorial forests lie the great grasslands, grass 10 to 15 feet high, with scattered trees. These grasslands occur where a distinct dry season prevents a survival of forests. Hence, the summers are similar to equatorial areas and winters are similar to desert lands.

d. In the variable climatic belt we find coniferous (evergreen) forests where rainfall is heavy throughout the year as on the northwest coast of North America. The eastern part of continents with summer convection showers and winter cyclonic storms are usually forested by hardwood trees, such as oak and maple. Such forests have been removed for agricultural practices wherever the surface was not too steep.

e. Between the eastern hardwood and the western softwood (coniferous) forests, the prairies and short grass plains lie in the rain shadow of high mountain ranges. Visibilities and ceilings are generally excellent in grassland regions. Precipitation is largely of the summer shower type.

f. Polar tundra vegetation is low and sparse, indicating low temperatures and relatively light precipitation. Good flying weather prevails nearly all the time over the tundras.

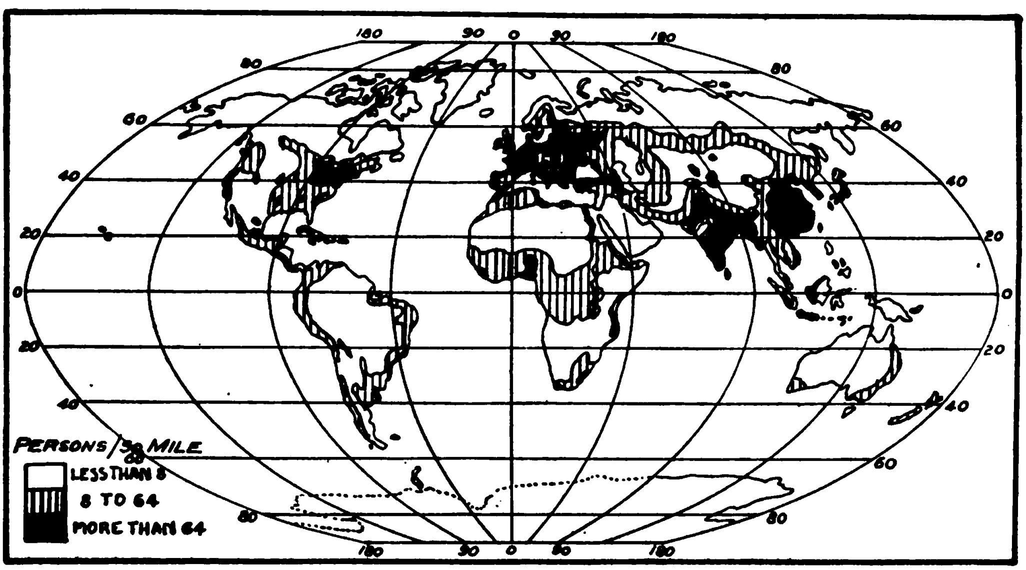


FIGURE 113.—Population.

125. Population.—*a.* Four regions have very dense population: (1) eastern Asia (China, Japan), (2) southern Asia (India, East

Indies), (3) northwestern Europe, and (4) northeastern North America.

b. The greatest industrial development has been made by the peoples of northwest Europe, eastern United States and Japan. What climatic factors probably aided such progress?

c. China's and India's large population, largely agricultural, reflects the warm, moist climate where food crops may be grown throughout most of the year. Monotonous weather day and night, week after week, seems to hinder modern industrial development.

QUESTIONS

1. Are densely populated areas in highlands or lowlands? Near coasts or inland?

2. In which climatic region do most people live?

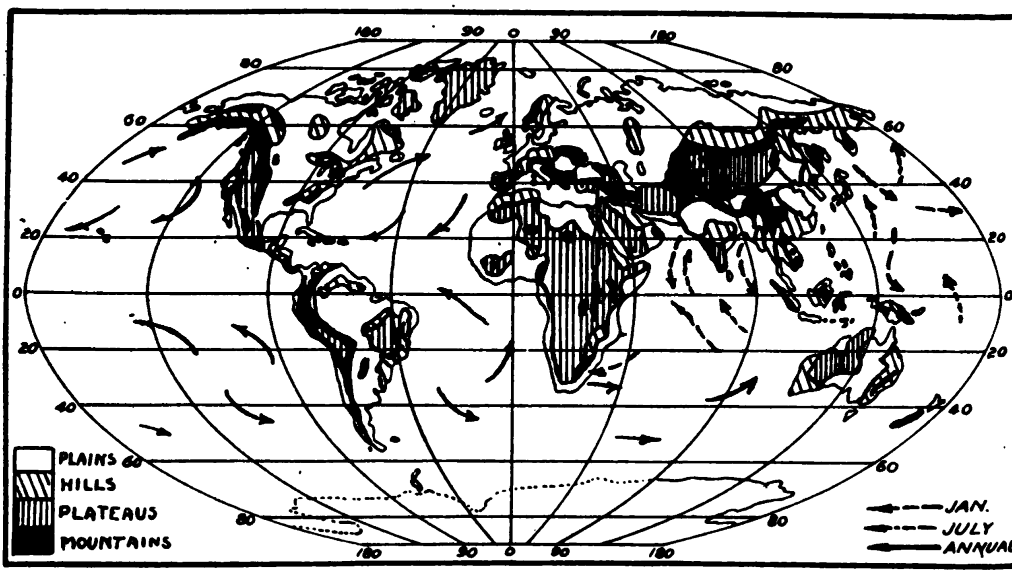


FIGURE 114.—Surface features.

126. Surface features (terrain) and their effects.—*a.* Observe the trend of major mountain systems. The uniform climatic belts which would be found on an earth with uniform surface are altered by mountains rising across the path of prevailing winds. In tropical areas, windward slopes are covered with dense forests while at a short distance away, on the leeward slopes, very dry conditions exist. Likewise, in the middle latitudes, great north-south mountain ranges have rainy western slopes with near desert conditions to the east.

b. Irregular land surface interrupts the flow of air, causing turbulence which may at times be a serious hazard. Cooling of air forced upslope increases cloudiness, thereby obscuring mountain peaks.

Where ascending air is conditionally unstable, thunderstorms will be common; if the temperature is low, icing adds another hazard to flying through clouds in mountainous regions.

c. Flying over level terrain is generally free of most of the dangers found over rough territory. However, low ceilings, fog and poor visibility, together with frontal conditions, necessitate alertness on the part of all pilots.

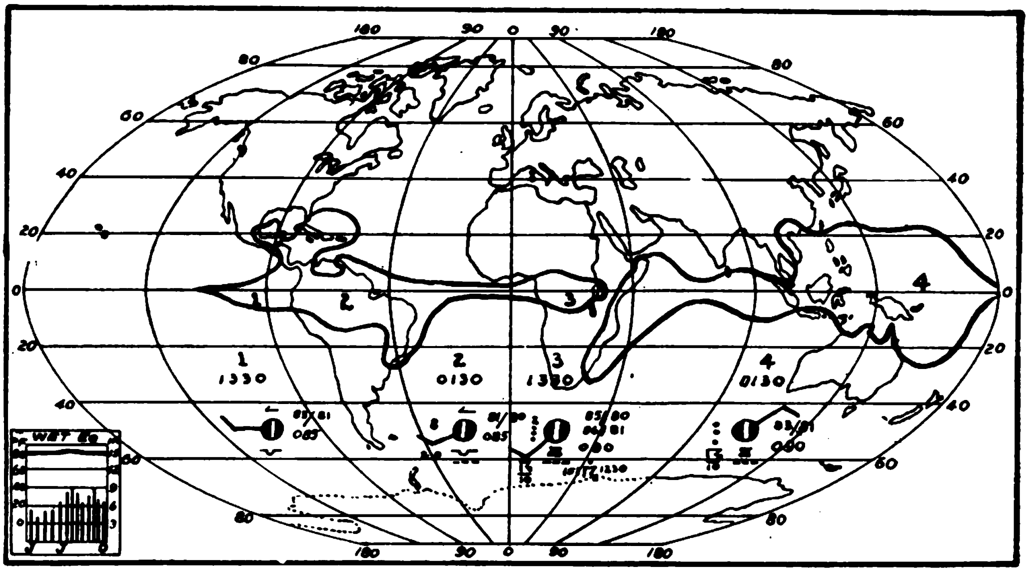


FIGURE 115.—Equatorial climate.

127. Equatorial regions (wet-hot).—*a.* Over low land areas along the equator, the temperature is always high, day and night, with only a few degrees variation throughout the year. The continuously hot, moist weather makes life for the white race almost unbearable. However, a slight rise in elevation brings enough variation, cooler nights and drier atmosphere, so that whites who must live here will be found on the hills and plateaus.

b. Plantation agriculture will appear to the flier as openings in a vast, dense jungle.

c. Instrument flight should not be undertaken except for very short periods of a few minutes and then only for the purpose of ascending or descending through layers of stratus clouds. Weather over the ocean is favorable for flying during daylight hours at altitudes above 10,000 feet. Cumulo-nimbus clouds at night make flying hazardous over the ocean in the equatorial region.

QUESTIONS

1. What is the probable maximum and the minimum temperature at stations 2 and 3?

2. Which weather elements will affect your comfort most?

3. Judging from temperature reports, would you expect general onshore or offshore winds during the daytime?

4. Would flying weather be better over land at 1000 or 1500 o'clock?

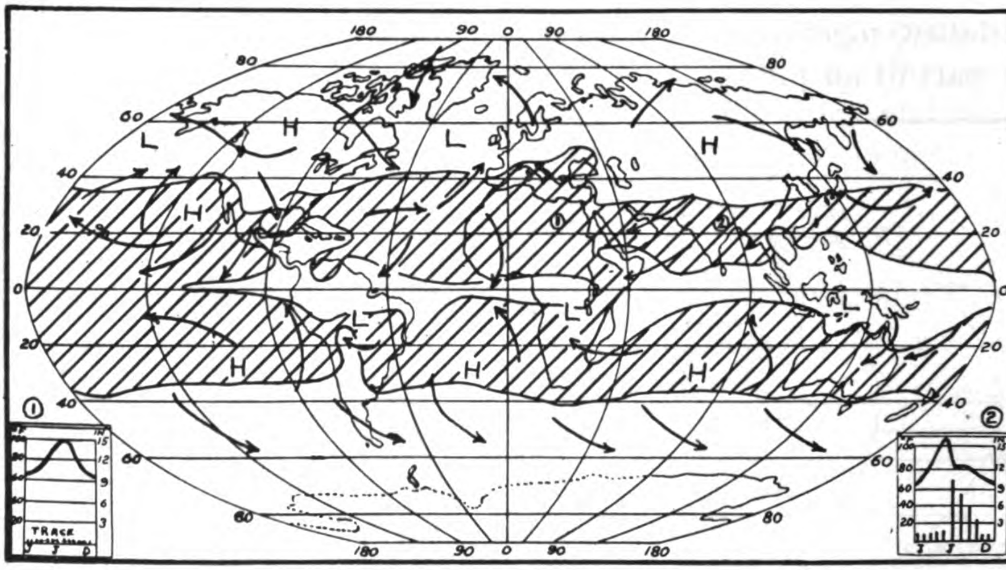


FIGURE 116.—Tropical climate, January winds.

128. Tropical regions.—*a. January.*—(1) High pressure circulation dominates the region of tropical dry lands. Winds are light and steady, blowing outward from high pressure centers. On the equatorward side the winds are known as Trade Winds because of their regularity in blowing commercial sailing vessels across the oceans. These northeasterly and southeasterly winds influence flight time materially as they aid or hinder planes on east-west routes.

(2) Cloudless sky for long periods make this one of the most favorable flying regions of the world.

(3) In sharp contrast to the monotonous, hot, moist equatorial region, temperatures in the tropical areas range from cool nights to very hot days because of the clear skies which freely permit insolation and terrestrial radiation.

QUESTIONS

1. What protection would you need when sleeping in a desert?

2. How might dust or sand storms injure planes and pilots?

3. In what way would emergency food supplies differ for tropical and equatorial flying?

4. What direction is the wind over the Indian Ocean in January?

b. July.—(1) Near the poleward margins of the tropical belt, unequal heating of land and ocean bring seasonal weather such as occurs in India. Over central Asia in summer a pronounced "low" develops with onshore winds moving inland from all sides. Eastern and southern Asia therefore get very heavy precipitation which is due in a large measure to the presence of high mountains and plateaus. Warm, unstable tropical air forced upslope in these regions give widespread torrential rain from cumulo-nimbus clouds.

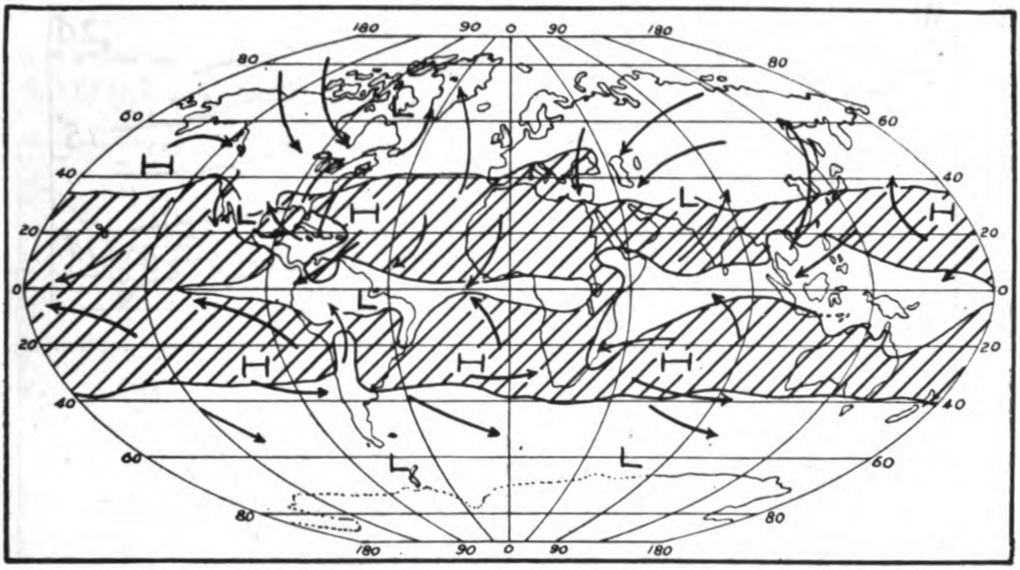


FIGURE 117.—Tropical climate, July winds.

(2) The Asiatic low is so extensive that a pressure gradient exists in July from the tropical high south of the Equator all the way into central Asia. Therefore, the southeast Trade Winds cross the Equator and are then deflected to the right, becoming steady southwest winds blowing across the Indian Ocean. Mountainous islands of the East Indies group receive heavy rainfall on their windward slopes which reverse with the monsoon seasons. Dense and almost impenetrable tropical forests cover most of these islands except where plantations have been established by peoples from the middle latitude countries.

(3) Similar conditions are found in the West Indies but to a lesser degree. The monsoon winds are not nearly so well developed but the summer low and winter high do exist in the western world, especially over North America.

QUESTIONS

1. From what high does the air come which flows into southern United States in summer? Is it stable or unstable? Why?

2. Are thunderstorms more common in Florida in summer or in winter? Why?

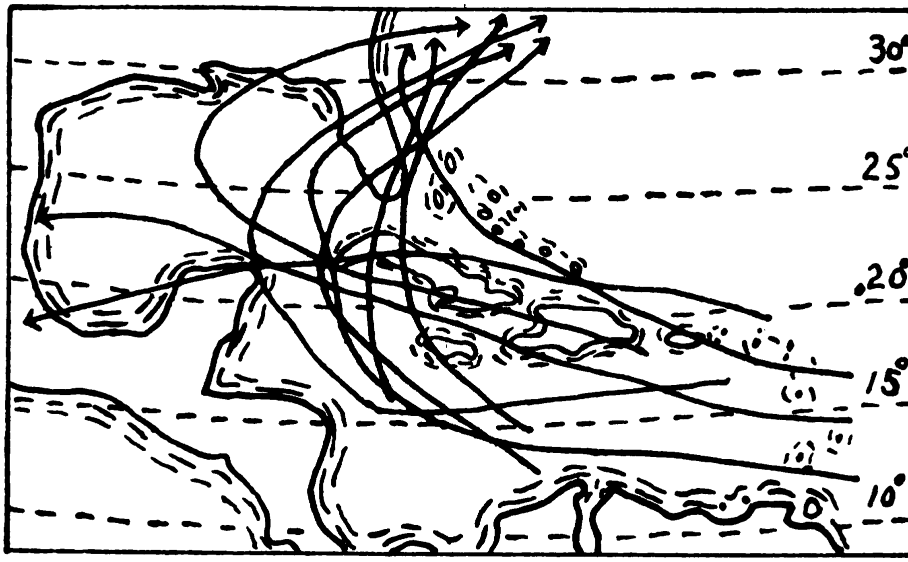


FIGURE 118.—Typical hurricane tracks in the West Indies region, August, September, and October.

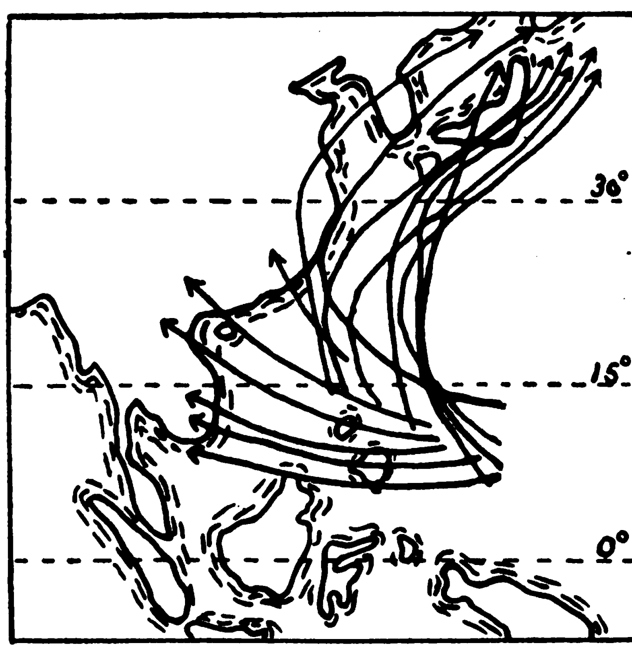


FIGURE 119.—Generalized typhoon tracks in the China seas, all seasons.

c. *Hurricanes and typhoons.*—Tropical cyclones called hurricanes and typhoons originate near the margin of the doldrum belt. Dangerous wind velocities, low ceilings, intense precipitation, and strong vertical currents render hurricanes impossible flying areas. Planes on the ground may be damaged unless securely tied down. In peace

times hurricane movements may be followed closely on weather maps but in war reports are lacking. Therefore, some knowledge of the extent and behavior of such storms is imperative for pilots flying in areas frequented by them.

QUESTIONS

1. Do Asiatic typhoons rotate clockwise or counterclockwise?
2. Could you make use of tailwinds near the edge of a hurricane?
3. What is the average forward speed of a hurricane center?
4. Is the diameter of a hurricane likely to be 60 miles, 600 miles or 6,000 miles?

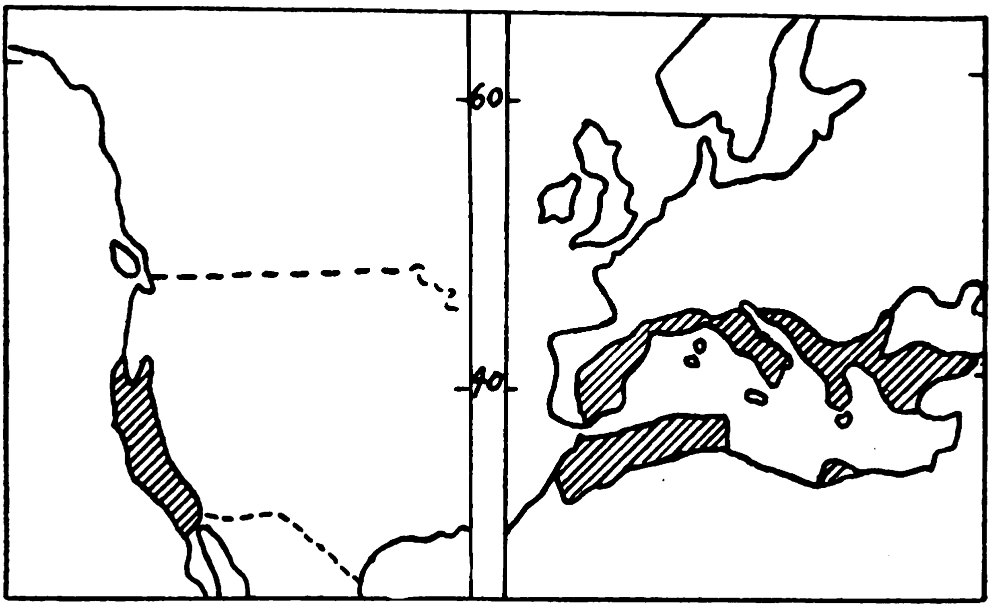


FIGURE 120.—Dry summer subtropical climatic regions.

d. Mediterranean climates.—(1) Along windward coasts of continents and on the poleward margins of the tropical belt rather well defined climatic regions occur which are characterized by hot, dry summers and mild, moderately rainy winters. Southern California and the Mediterranean lands are the best known areas of this type.

(2) In summer, the contrast between temperatures over the hot deserts and cooler ocean water results in a strong sea breeze along the coast. The abundance of salt particles produce haze and also serve as nuclei for condensation of moisture into dense fog. Fog is the most frequent hazard of a serious nature along the west coast. The sea breeze strengthens the onshore wind in summer. It reaches its maximum strength in the afternoon and at that time the fog begins to roll in from the ocean. This continues till late at night and the

fog persists until sunrise when the surface convection begins lifting the ceiling which becomes unlimited later in the morning.

(3) During the winter, the Great Basin high frequently causes off-shore winds with clear skies and unusually high temperatures. Strong, warm to hot winds flow down the mountain canyons, at times reaching dangerous velocities. When flying near these mountains, pilots should be aware of the extreme turbulence in such winds. Quite similar conditions occur along the Mediterranean shores of Europe and small areas along the southern tip of Africa and Australia.

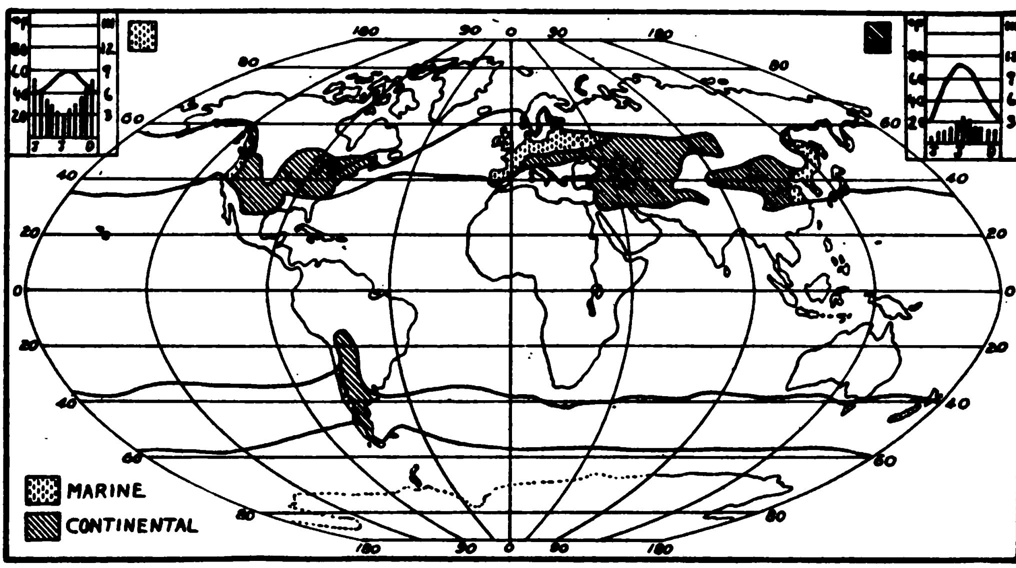


FIGURE 121.—Variable climate.

129. Variable climatic region.—*a. General.*—(1) Poleward from the tropical regions, winds are deflected to the east so that the name Prevailing Westerlies is generally applied. In this region, lying roughly between 35° and 60°, in the so-called middle latitudes, seasons are more distinct than nearer the equator. Summers are warm to hot, and winters are cool to cold. The region is characterized by extra-tropical cyclones which result from the interaction of warm tropical westerly winds and cold, dry polar easterlies.

(2) The frequent passage of cyclonic storms brings sudden temperature changes, wind shifts, variations in pressure, and precipitation. In general it may be said that variability of weather is stimulating to the human race, hence we find here the greatest economic activity and the most aggressive peoples. Most military activity is apt to be centered in the middle latitudes, but increasing amounts of combat in the tropical region will be carried on in an attempt to control tropical raw materials.

QUESTION

1. Would you expect to find better flying weather over the poleward or equatorward margin of the variable belt? Why?

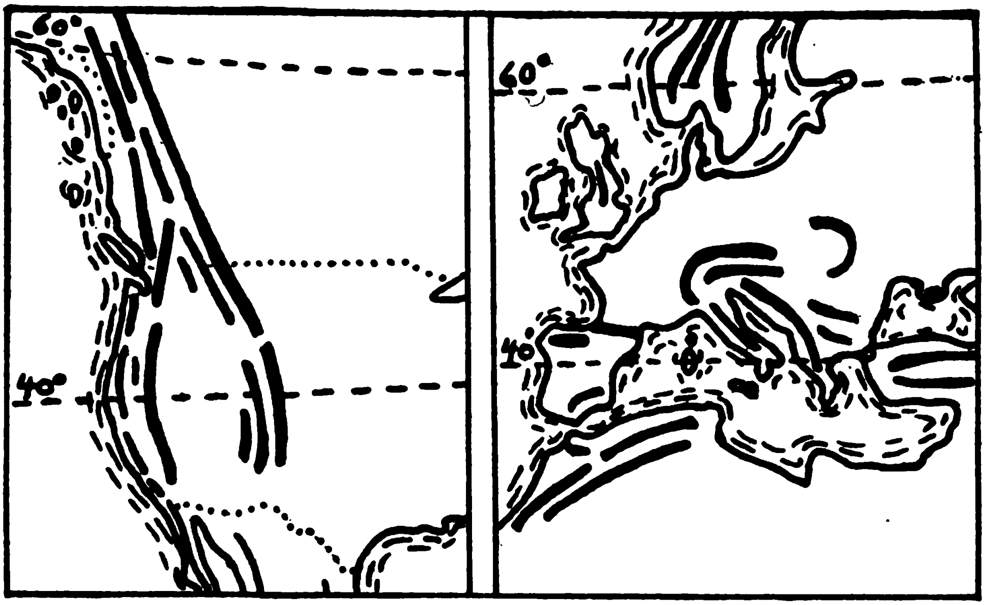


FIGURE 122.—Direction of principal mountain ranges of western North America in contrast to those of western Europe and the Mediterranean region.

b. Marine influence.—The climate of windward coasts and of islands in the variable region is distinctly marine in character. Marine influence, giving modified temperature, and moderate to heavy precipitation, is limited to a narrow strip along the west coast of North America by the presence of high north-south mountain ranges. Europe has no such barrier because the mountains have in general an east-west trend. Marine influence extends inland many miles over the great plains of Europe, gradually fading out as the moisture is precipitated. Stratus and fog is, therefore, more widespread over the countries of western Europe than over North America. However, icing and thunderstorms, such as are found over the high mountains of Washington and Oregon, are seldom encountered over western Europe.

QUESTIONS

1. What effect does marine climate have upon bombing cities?

2. In planning a bombing raid would you choose cyclonic or anticyclonic conditions?

c. Continental influence.—(1) Extreme temperature ranges, diurnal and seasonal, occur throughout the middle latitudes in the interior

of continental masses. Precipitation, which is less than found in the marine climates, falls largely as summer convection showers. Frequent polar air invasions and frontal activity throughout the winter varies all weather elements. Stratus and fog may cover wide areas, reducing ceiling and visibility so low that contact flying is impossible for days at a time.

(2) Flying conditions generally improve westward from the industrial centers of eastern United States because of the decrease of smoke and moisture. The drier portions of variable continental regions are subject to serious dust and sand storms and an occasional tornado. Near the poleward margins snow flurries, set off by turbulence over rough terrain, frequently reduce visibility seriously during the winter season.

(3) Mountains near the east coasts also tend to repeat conditions encountered in the west but to a lesser degree.

d. East coasts of the variable climatic region.—Typical of flying weather in this region is the information contained in the following letter from a former Randolph Field navigation instructor now on duty in Newfoundland.

"Have been gathering some information that should be valuable in the Ground School and will try to give you the high points; undoubtedly some of the cadets will see service in a climate comparable to this and a few hints while in school sure won't do them any harm.

"*Weather and navigation.*—A serious problem; very few landing fields and no auxiliary fields—complicated by the extreme high winds which to make good a true course (including the variation) will many times cause the pilot to head east by compass to make good a true course of north. This seems entirely out of place and again causes the pilot to be in a considerable strain. I had this happen to me on one flight. The many fronts that pass in rapid succession cause much trouble in contact flying, making on top flying most desirable. Many snow flurries are encountered in nearly every flight. When you try to fly contact, you are much worse off than on top where large holes can frequently be found. The winds above the clouds are usually 30 miles per hour stronger than those found below the clouds, and always must be reckoned with before going on top. As a general rule, the winds blow from 270° to 360°. There are six large lakes on this island that never freeze. They are excellent landmarks for pilots lost or undecided as to position. Ground speed can gain or lose 70 mph in a flight of 200 miles and should be checked constantly. Good computer work comes in handy.

"*Mechanics and motors.*—The knowledge that your next landing place may be 530 miles away causes us to realize the importance of the mixture control. A local flight may turn into a race with the weather. Heat control is very important. You can run into carburetor icing when you least expect it. The manifold gage is O. K. to watch, but the best idea is, in case of doubt, apply heat. Outside air temperatures (30° to 40° minus) cause serious icing on inner glass windows. To help remedy this I have a ten-cent store scraper with a razor blade in it; also use a rubber hose attached to air intake so that a stream of air blows on whichever window you want to keep defrosted.

"*Proper knowledge of use of dilutor system.*—You dilute here after every flight. Flight instruments are affected by the low temperatures. They should be tested for operation before every flight. Never take off with frost, snow, or ice on wings."

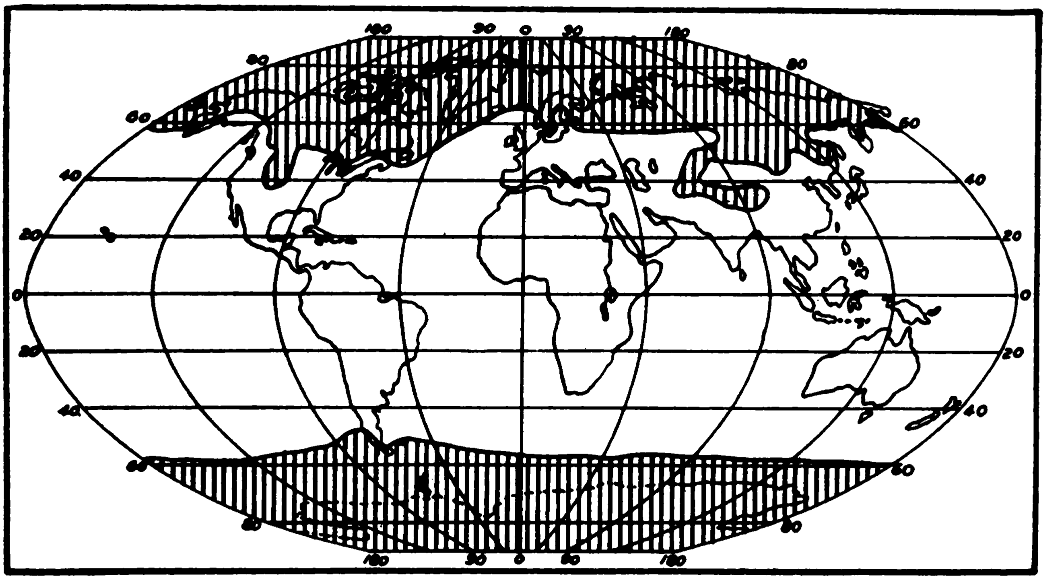


FIGURE 123.—Polar climate.

130. Polar climate.—*a.* During much of the year in high latitudes and at high altitudes in mountainous regions, the temperature is too low to permit sufficient agricultural production for the support of more than a sparse population. Flying over polar lands will be mainly for the purpose of shortening routes.

b. In general, the weather is excellent for flying but for an occasional blizzard during the long winter night. Another exception will be noted along the windward coasts where fog, low stratus and icing may handicap flying at low altitudes.

c. Emergency landings may be made on the frozen tundra in winter and on the numerous swamps and shallow lakes in summer.

d. Extremely low temperatures have been recorded; for example, −90° F. occurred in Siberia. The summers are short but with long hours of sunshine; temperatures of above 100° F. are not uncommon. Protection for the pilot in case of an emergency landing is perhaps more essential than flying weather information in polar climates.

QUESTION

1. Why are polar skies so much less cloudy than middle latitude skies? (Consider temperature, pressure and moisture.)

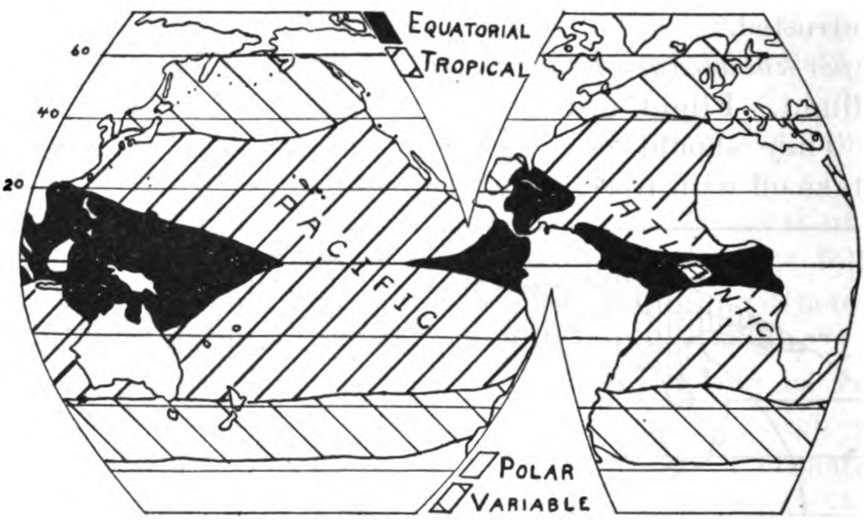


FIGURE 124.—Ocean weather.

131. Ocean weather.—*a. North Atlantic.*—(1) Winter in the Atlantic north of 40° may be classified as variable. The Icelandic low which governs circulation in this region usually gives moderate to strong westerly winds. Frequent intense migratory cyclones with severe frontal activity make this one of the more dangerous flying areas. Cloudy skies may be expected 70 percent of the time. Fogs are frequent, especially with warm fronts.

(2) Summer brings considerable improvement. Gales decrease from 30 percent or 40 percent of the time in winter to 5 percent or 10 percent in summer. Migratory lows are much weaker. Cloudiness and fogs decrease except over the Grand Banks where fogs are about twice as frequent.

QUESTIONS

1. What would you consider the most difficult weather element or condition for a pilot flying between Newfoundland and Scotland?
2. List other hazards in order of danger to pilots.

b. Tropical Atlantic.—(1) Weather varies only slightly between summer and winter in the tropics (roughly 20° to 40° latitude). Throughout the year the permanent Atlantic high (also called Bermuda high or Azores high) dominates circulation. In the northern half the winds are fairly steady from the southwest while in the southern half winds known as Trades blow steadily from the northeast. Gales are rare.

(2) Cloudiness covers the sky about 50 percent of the time in winter and 40 percent in summer. Fogs are infrequent except over the cold current near the Canaries.

(3) An occasional hurricane moves across the western part in a northerly or northeasterly direction.

c. Equatorial Atlantic.—(1) Tropical conditions merge gradually with the equatorial near 10° to 15° north latitude. The doldrum belt is narrower over the ocean than over the continents and does not extend south of the equator in the Atlantic. Daylight flying above 10,000 feet is unhampered by bad weather but night flying may encounter dangerous cumulo-nimbus clouds.

(2) Between 10° and 20° north latitude, hurricanes originate and travel westward, attended by gales and severe turbulence.

(3) Fogs are almost unknown, but visibility is poor much of the time.

d. Tropical region in South Atlantic.—(1) The general circulation about the South Atlantic high, centered mid-ocean near 30° south latitude, is in a counterclockwise direction. All this tropical area is in the belt of southeast Trades except in the western part where the winds are east and northeast off the southern coast of Brazil.

(2) Hurricanes do not occur in the South Atlantic and gales are rare. Cloudiness and fogs do not seriously interfere with flying except near the African coast where cloudiness increases to 65 percent. Pilots returning from the tropical coast of western Africa report that dense haze reduces visibility so low that landings are very hazardous.

e. Variable belt in South Atlantic.—(1) Poleward beyond 30° south latitude, winds become westerly. Their velocity during the winter averages as follows:

Latitude:	Mph
30°	16
40°	23
50°	35

Gales increase from 5 percent of the time at 30° to 30 percent at 50° south latitude. Summers show only a slight improvement.

(2) Cloudiness also increases with higher latitude from 55 percent at 30° to 70 percent at 50° latitude. In summer, fogs are reported 1 percent of the time at 30° and 15 percent at 50°. They are about one-half as frequent in winter.

QUESTIONS

1. In crossing the Atlantic from east to west between 10° north latitude and 40° north latitude at about what latitude would you find the most favorable tail winds?
2. How would the frequent and rapid passage of fronts affect navigation over the North Atlantic?
3. Mention two ways by which you might avoid icing when flying across the North Atlantic in winter?
4. Make a rough sketch to show circulation around the Bermuda high.

f. North Pacific (35° north latitude to 60° north latitude).—(1) Weather in the Pacific is similar to that of the Atlantic in many ways. Circulation is well developed around the Aleutian low during the winter. Strong westerly winds blow across the area carrying along frequent, intense migratory cyclones with gales from 15 percent to 20 percent of the time. About 70 percent of the sky will be cloudy.

(2) In summer, the North Pacific high dominates the circulation. Winds are moderate westerly with gales from 5 percent to 10 percent of the period. Cloudiness is extreme, averaging about 80 percent. Widespread fog may be encountered in the west about 35 percent of the time while along the California coast they are found 5 percent to 10 percent.

g. Tropical Pacific.—Excellent flying weather is found nearly all the time over the tropical Pacific. Circulation about the North Pacific high produces steady northeast Trade Winds over most of the area, except in the China Sea and a narrow belt of doldrums near the continents. The western part, including the China Sea, is subjected to destructive storms known there as typhoons which are like the hurricanes in the Atlantic. Near the coast of Asia monsoon winds are characteristic.

h. South Pacific.—Weather in the South Pacific is like that of the South Atlantic with the one notable exception that typhoons occur in the Pacific but not in the Atlantic south of the Equator.

QUESTIONS

1. What climatic regions would you traverse when flying the shortest route from San Francisco to Tokyo?

2. Suggest a route that would have better flying weather between the cities in question 1.

3. Give the direction of sunrise along the 40th parallel north in June. How might you use such information if you were flying across the ocean?

4. Does the air over the oceans in low latitudes tend to become more or less stable after sunset? Why?

5. How is information secured for drawing ocean weather maps during peace time? How in time of war?

Appendix I

WEATHER MAP

1. Symbols and placing of data around the station circle.—In order to plot all information in an exact manner with economy of space, it is necessary to employ symbols and figures. The symbols to be used, except for slight modifications, are those which have been adopted internationally. The arrangement of the information around the station circle is given below, with the symbols. The positions of the land stations are shown by small circles. The entry of all observations will be made in black ink. Whenever an observation of any element is missing it will be indicated by placing a dash or short horizontal line in the space allotted for this entry.

a. (1) *Arrangement of information around station circle.*

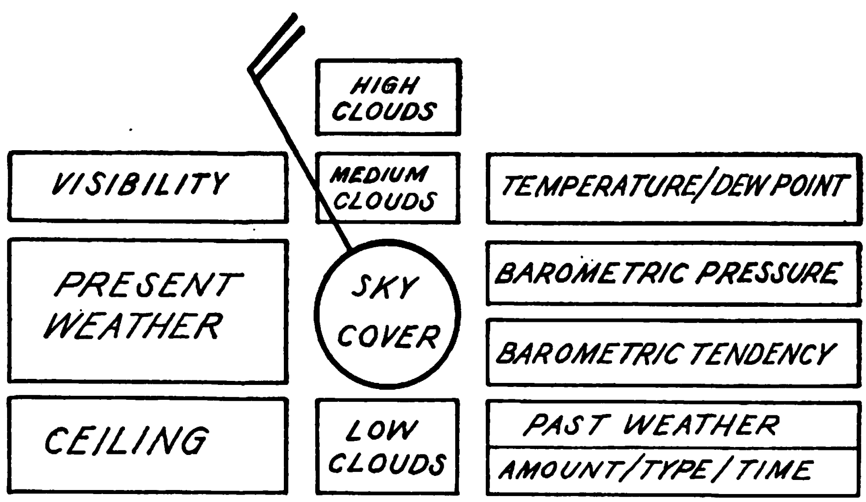


FIGURE 125.

(2) *Examples and interpretation.*

FIGURE 126.

Wind	North, force 5 (about 20 mph)	West, force 3 (about 9 mph)
Sky cover	10/10 (overcast)	clear (none)

Visibility	2 miles	12 miles
Present weather	thunderstorm with rain	none
Ceiling	600 feet	unlimited
Temperature	58° F.	25° F.
Dew point	57° F.	18° F.
Barometric pressure	1,013.2 millibars	996.6 millibars
Barometric tendency	down, then up; +2.5 millibars	down steady; −0.8 millibars
Past weather	.57 inch of rain with thunderstorm beginning at 1100 o'clock	trace of snow which stopped falling at 1600 o'clock
Clouds	cumulo-nimbus moving toward the southeast	

b. Present weather symbols and coloring.—(1) *Precipitation.*

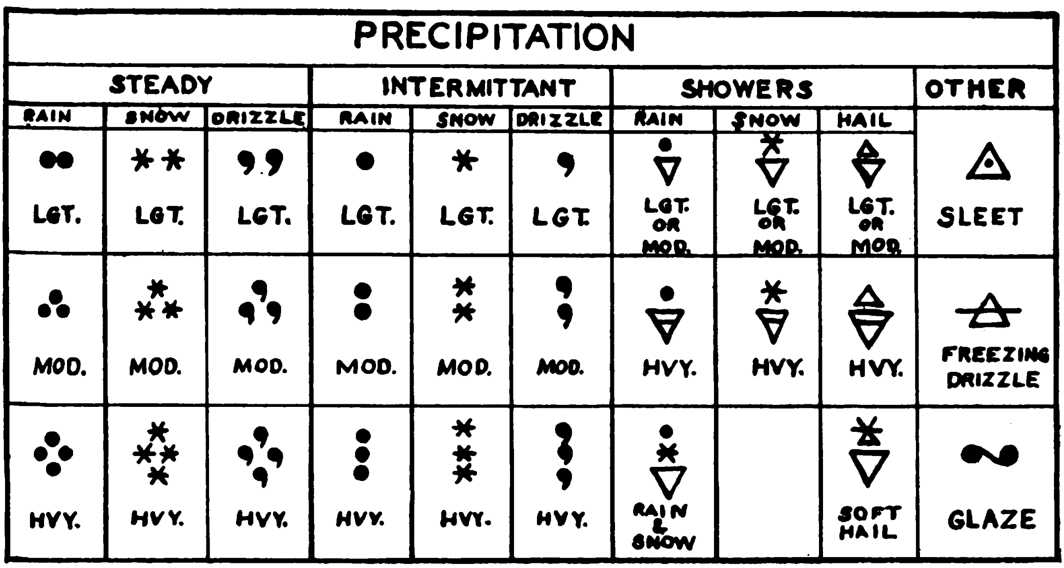


FIGURE 127.

(*a*) Steady precipitation is represented by solid green shading.

(*b*) Intermittent precipitation is represented by green crosshatching.

(*c*) Showers are represented by duplicating the symbol in green.

(*d*) Other precipitation is represented by green crosshatching.

(2) *Fog.*

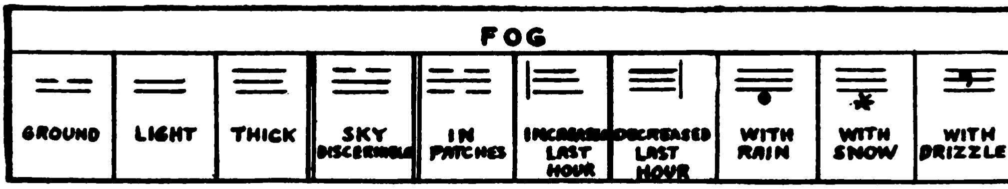


FIGURE 128.

(*a*) Fog alone is represented by solid red shading and symbol underlined with red.

(*b*) Fog with precipitation is represented by solid red shading, crosshatched with green and symbol underlined with red.

(3) *Thunderstorms.*

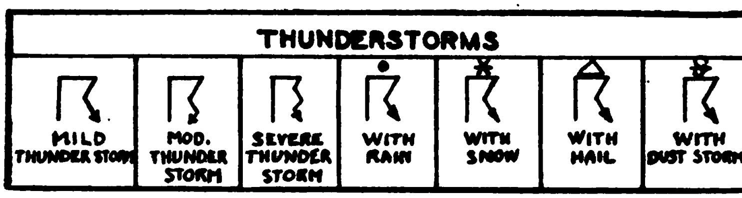


FIGURE 129.

A thunderstorm is represented by duplicating the symbol in green and underlining with red.

(4) *Dust storms and drifting snow.*

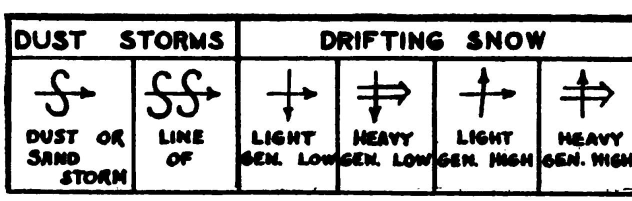


FIGURE 130.

A dust storm or drifting snow is represented by duplicating the symbol in green and underlining with red.

(5) *Squalls and miscellaneous.*

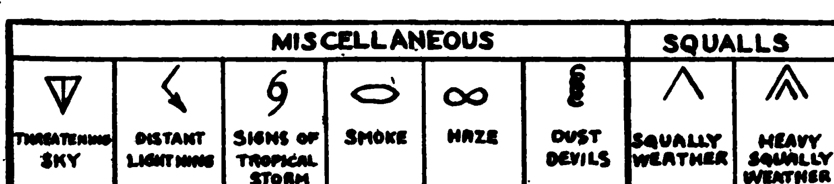


FIGURE 131.

These are represented by underlining symbol with red.

c. Modifying symbols.

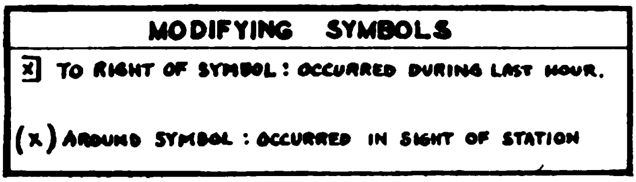


FIGURE 132.

d. Clouds.

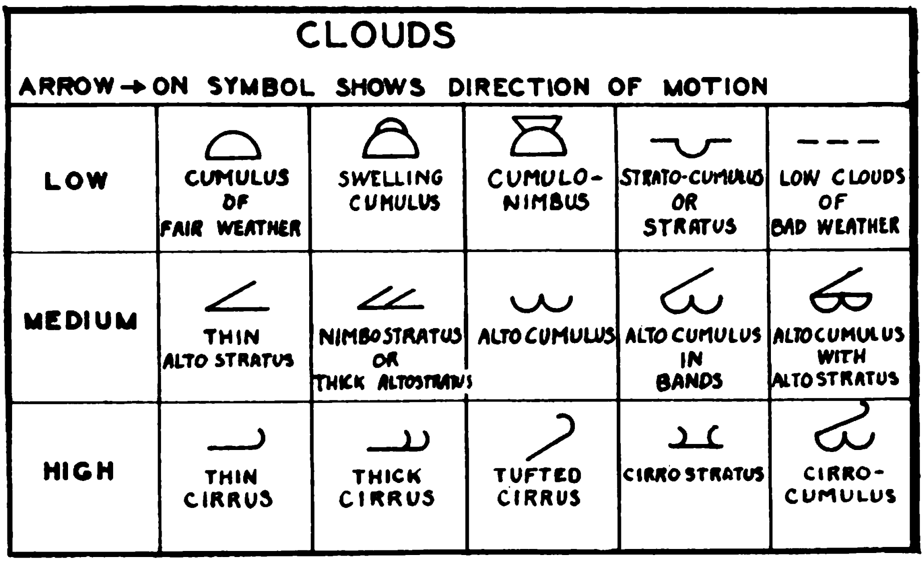


FIGURE 133.

e. Sky cover.

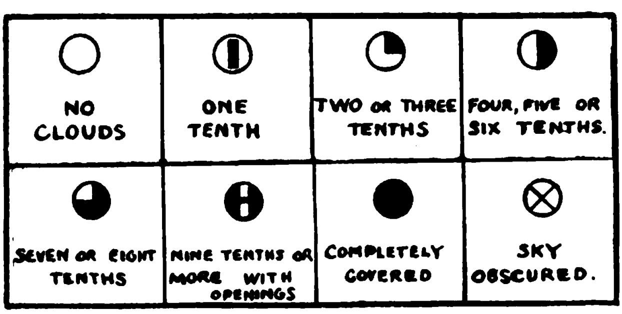


FIGURE 134.

f. Barometric tendency.

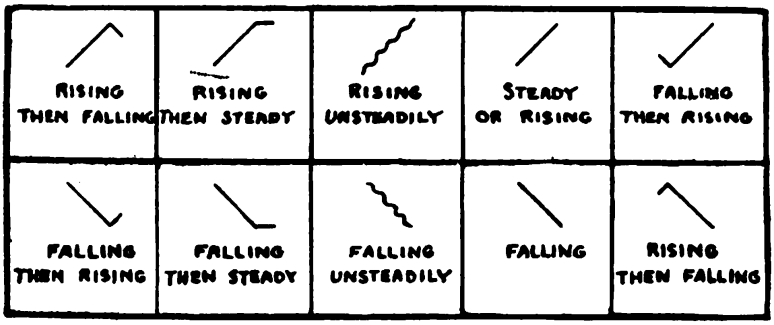


FIGURE 135.

Barometric tendency symbols show schematically which way the pressure has changed. The amount of total change for the last 3 hours is given in tenths of millibars and placed to the right of the symbol.

g. Barometric pressure.—Pressure is given in millibars and tenths, but only the last 3 digits of the complete number is entered. For instance, a number 098 would indicate a pressure of 1,009.8 millibars.

h. Temperature.—Temperature is entered in whole degrees Fahrenheit.

i. Dew point.—Dew point is entered in whole degrees Fahrenheit.

j. Visibility.—Visibility is plotted directly in miles and fractions of a mile.

k. Ceiling.—Ceiling is entered in hundreds of feet; e. g., 25 indicates a ceiling of 2,500; 0, a zero ceiling; u, an unlimited ceiling.

l. Wind direction.—Wind direction is shown by an arrow flying with the wind. The station circle is the head of the arrow. Velocity is indicated by the number of barbs on the tail of the arrow. A calm is indicated by circumscribing the station circle in black. The Beaufort wind scale is given in table II, paragraph 31.

2. Fronts.

Type	*Symbol on map*	*Coloring*
Stationary		Alternate red and blue dashed line.
Cold, surface		Blue line.
Cold, aloft		Dashed blue line.
Warm, surface		Red line.
Warm, aloft		Red dashed line.
Occluded		Purple line.
Cold, indistinct	o o o o	Blue dots.
Warm, indistinct	o o o o	Red dots.
Occluded, indistinct	o o o o	Purple dots.
Frontogenesis	——→FG←——	FG (purple).
Frontolysis	←——FL——→	FL (purple).

Direction of movement is indicated by triangles or semicircles.

3. Basic air mass symbols.—*a.*

Source	*Symbol*	*Coloring*
Arctic	A	Blue A
Polar	P	Blue P
Tropical	T	Red T
Equatorial	E	Red E

The modifying symbols (warm or cold; maritime or continental) are colored the same as the basic symbol.

b. For weather map symbols see chart 1 (insert at back of manual).

Appendix II

TELETYPE WEATHER REPORTS

1. Explanation of reports.—See chart 2 (insert at back of manual).

2. Abbreviations.—*a*. Often there is some special weather information which the weather observer wishes to send in the report in addition to that provided for in the regular code. In this case remarks are made at the end of the report in standard abbreviations, and symbols. A few of the most important common abbreviations are listed below.

ALT	Altitude.
APOBS	Airplane weather observations.
ARV	Arrive.
BINOVC	Break in overcast.
BRK	Break.
BRONO	Broadcast not operating.
CFR	Contact flight rule.
CHG	Change.
CIG	Ceiling.
CLD	Cloud.
CLR	Clear.
CU	Cumulus (cloud).
DRZL	Drizzle.
ETA	Estimated time arrival.
FANOT	Fan type marker not operative.
FCST	Forecast.
GNDFG	Ground fog.
HZY	Hazy.
ICC	Icing.
IFR	Instrument flight rule.
IOVC	In overcast.
IPV	Improve.
LTNG	Lightning.
MDT	Moderate.
MSL	Mean sea level.
MSTK	Mistake.
NOOPV	Not operative.
OBSC	Obscure.
OTP	On top.
OVC	Overcast.
OVR	Over.
PCPN	Precipitation.
PIBAL	Pilot balloon sequence reports (upper winds).
PIREPS	Pilot reports.
QTR	Quarter.
QUAD	Quadrant.
RAOBS	Radio meteorological soundings.
RANOT	Radio range not operative.
RGD	Ragged.
RNWY	Runway.
RTE	Route.
SNW	Snow.
SQAL	Squall.
SCTD	Scattered.
STM	Storm.
STN	Station.
THD	Thunderhead.
THDR	Thunder.
THK	Thick.
THN	Thin.
TLTP	Teletype.
TMP	Temperature.
TOVC	Top of overcast.
TSTM	Thunderstorm.
TURBT	Turbulent.
UNSTDY	Unsteady.
VSB	Visible.

VSBY	Visibility.	XTSV	Extensive.
WB	Weather bureau.	ZONOT	Station location marker, ultra high frequency, not operating.
WND	Wind.		
XLNT	Excellent.		

b. The above short list includes many of those abbreviations commonly found in weather reports. Many others are used but they are usually more obvious and can be translated at sight. The following examples illustrate the use of abbreviations in weather remarks.

PIREPS TOVC 6000 MSL	Pilot reports top of overcast at 6,000 feet above mean sea level.
LTNG NW	Lightning to the northwest.

Appendix III

WINDS ALOFT (TELETYPE)

1. Standard groups in numerical code.

IIEE Oddvv ddvv 2ddvv ddvv 4ddvv ddvv 6ddvv ddvv 8ddvv ddvv oddvv ddvv 2ddvv ddvv 4ddvv

(As many as necessary up to the height where the balloon was lost.)

2. Symbols.—*a.* The digits 0, 2, 4, 6, etc., at the beginning of each 5-digit group indicate the altitude of the level at which the wind is being reported, as shown in the accompanying table. The 4-digit groups represent the intermediate altitudes (1,000, 3,000, 5,000, etc.), according to their position in the report. Above 15,000 feet, reports are made for each 5,000 feet. These are reported as 5-digit groups.

0=Surface	2=12,000 feet above sea level.
2=2,000 feet above sea level.	4=14,000 feet above sea level.
4=4,000 feet above sea level.	5=15,000 feet above sea level.
6=6,000 feet above sea level.	0=20,000 feet above sea level.
8=8,000 feet above sea level.	5=25,000 feet above sea level.
0=10,000 feet above sea level.	0=30,000 feet above sea level.

(It will be noted that the same digit is sometimes used for more than one level. The position of the group in the report indicates which level is intended.)

b. II=Station call letters.

c. EE=Time of observation to the nearest whole hour, E. S. T., on the 00-24 hour basis.

d. dd=Direction from which wind is blowing. *Wind directions are given to 36 points;* round out the direction to the nearest *zero* and divide by 10, for example:

88° reported as 90° and coded as 09
183° reported as 180° and coded as 18
West wind; i. e., from 270°, coded as 27
North wind; i. e., from 360°, coded as 36
00 *is not a north wind.* It indicates a calm (no wind).

e. vv=Velocity of wind in whole miles per hour. If velocity is between 100 and 200 mph, only the tens and units digits are used, and the corresponding dd is increased by 50. If the velocity is 200 mph or greater it is coded completely, preceded by a slant (/) as follows: dd/vvv. Wind 52 mph is reported as 52, 125 mph as 25 and 208 mph as /208.

3. Examples.

CX11 02015 2017 82135 2250 02273 2381 22397 2499 47503

Read as follows:

Cheyenne 11 A. M. E. S. T. (elevation of Cheyenne is 6133 feet)
Surface wind 200° at 15 mph
7,000 feet 200° at 17 mph
8,000 feet 210° at 35 mph
9,000 feet 220° at 50 mph
10,000 feet 220° at 73 mph
11,000 feet 230° at 81 mph
12,000 feet 230° at 97 mph
13,000 feet 240° at 99 mph
14,000 feet 250° at 103 mph

Appendix IV

FORECASTS

1. **Types.**—The following type forecasts are issued by Air Forces weather stations:

a. Regional forecast.—Weather conditions over a geographical area or region during a given period of time.

b. Terminal forecast.—Forecast conditions for a particular airport during a period from 24 to 36 hours.

c. Route forecast.—Weather at geographical points along the route normally covering a 6-hour period.

d. Trip forecast.—The weather at various stations along a route that a pilot will encounter on a particular trip.

2. **Elements.**—Elements of a forecast are given in the following order:

a. State of weather (overcast, broken, scattered, clear, or combinations thereof).

b. Precipitation (by type).

c. Ceiling (in thousands of feet if above 2,000 feet, in hundreds of feet if below 2,000 feet).

d. Visibility (in miles and fractions thereof).

e. Surface wind velocity (by direction and intensity).

f. Upper air wind velocities (by direction and intensity).

g. Best flying altitude (for route and trip forecasts only), that is, level of the most helping winds or least head winds.

3. **Examples.**—Examples of forecasts are given below:

a. Regional synopsis.—0700CS 9/4/38. Weak front along Texarkana, Dallas, Brady, Del Rio line will produce broken to overcast cloudiness and scattered thunderstorms along frontal zone. Weak cold front south of Houston, Pass Cavallo Laredo line will continue to produce thunderstorms with decreasing intensity dissipating during the night.

b. Randolph Field terminal forecast.—0700CS 7/1/38 to 2400CS 7/2/38. Broken stratus clouds becoming stratocumulus by 0730CS. Broken clouds decreasing to scattered by 0830CS, decreasing during period 0830CS to 1300CS and increasing 1400CS to 1600CS. Cumulus clouds clearing after dark—low stratus clouds forming 0200CS Tuesday overcast 0230CS to 0830CS scattered 0830CS to 1900CS—becoming clear 1900CS for remainder of period.

Ceilings 1,200 feet lifting to 1,800 feet 0700CS to 0830CS unlimited thereafter with base of cumulus at 5,000 feet after 1400CS—ceilings lowering after 0230CS Tuesday in stratus clouds to 1,000 feet lifting 0730CS to 0830CS to 2,000 feet and unlimited thereafter.

Visibility 12 to 15 miles.

Surface winds south to southeast 8 to 12 mph increasing during the afternoon 12 to 18 mph. Surface winds 2400CS to 0600CS decreasing to near 4 to 6 mph increasing thereafter 8 to 15 mph.

Winds aloft—below 8,000 feet south to southeast 15 to 25 mph—above 8,000 feet west to northwest 10 to 20 mph.

c. Route forecasts.—0700CS to 1300CS 7/1/38.

Randolph to Dallas to Shreveport. Cold front lying along Texarkana Gainesville line at 0700CS moving to Shreveport Dallas line by 1200CS. Broken clouds Randolph to Austin becoming scattered by 0830CS—scattered the remainder of the period. Scattered clouds Waco–Navasota during entire period—broken to overcast Dallas–Shreveport with thunderstorms developing by 1100CS.

Ceilings 1,200 feet Randolph to Austin lifting to 1,800 feet by 0830CS and unlimited thereafter. Ceiling unlimited Waco–Navasota during entire period. Ceiling Dallas–Shreveport 800 to 1,200 feet along frontal zone and less than 800 feet in scattered thunderstorms, improving to 1,500 feet after passage of front.

Visibility 12 to 15 miles, decreasing 3 to 5 miles in rain along frontal zone.

Surface winds south to southeast 8 to 12 mph shifting at Dallas to northwest 12 to 18 mph after 1200CS.

Winds aloft below 8,000 feet, south to southeast 15 to 25 mph above 10,000 feet west to northwest 10 to 20 mph.

Best flying level, 6,000 feet, net tail wind 15 mph.

d. Trip forecast.—For BT-9 from Randolph to Oklahoma City. Time of departure 1000CS 10/16/38.

(1) Randolph to Waco—high scattered clouds becoming broken in vicinity of Austin.

Ceilings unlimited to 8,000 feet in broken clouds.

Visibilities—unlimited.

Winds aloft—south to southeast 18 to 24 mph. Best flying level, 4,000 feet, net tail wind 15 mph.

(2) Waco to Hensley—high broken becoming high overcast. Light showers south of Hensley.

Unlimited ceilings to 8,000 feet with ceiling 4,000 feet in showers.

Visibility 15 miles becoming 5 miles in precipitation.

Winds aloft—southeast 15 to 24 mph. Best flying level, 6,000 feet, net tail wind 20 mph.

(3) Hensley Field to Ardmore—high overcast becoming low overcast with lower broken. Cold front will be encountered between Gainesville and Ardmore with violent thunderstorms.

Ceilings 3,000 to 8,000 feet in vicinity of front, becoming 1,000 to 1,500 feet after passage of front.

Visibility—5 miles decreasing to ¾ mile in frontal zone, increasing to 2 miles after passage of front.

Winds aloft—east below 4,000 feet 12 to 15 mph becoming southeast above 5,000 feet 20 to 25 mph. Severe turbulence in frontal zone. Best flying level, 8,000 feet, net tail wind 10 mph.

(4) Ardmore to Oklahoma City—low overcast becoming lower broken and lower scattered in vicinity of Oklahoma City.

Ceilings—lifting from 1,000 feet to unlimited vicinity of Oklahoma City.

Visibility—increasing from 2 miles to unlimited.

Winds aloft—northeast to north up to 5,000 feet becoming northeast to east above 5,000 feet. Velocities of from 15 to 20 mph.

Best flying level, 8,000 feet, net head wind 10 mph.

Appendix V

GLOSSARY OF TERMS

Absolute humidity.—The mass of water vapor present in a unit volume of air or the density of the water vapor.

Absolutely stable.—A vertical distribution of temperature, such that whether the air be dry or saturated, particles will tend to remain in their original level.

Adiabat.—A curve along which a thermodynamic change takes place without the addition or substraction of heat. In the case of the atmosphere, a "dry adiabat" is generally considered a temperature-height or temperature-pressure curve along which a rising or sinking air particle will fall providing no saturation occurs and providing that no heat is given to or taken from the particle in its path. Similarly a "wet adiabat" (saturation adiabat, condensation adiabat, or pseudo-adiabat) is a temperature-height or temperature-pressure curve along which the saturated rising particle will fall.

Adiabatic chart.—A thermodynamic diagram in which temperature is plotted against height or pressure (generally on a logarithmic scale or pressure to the 0.288 power) and in which dry and moist adiabats are constructed. The chief use of this chart is the evaluation of aerological soundings.

Adiabatic process.—A thermodynamic process in which no heat is transferred from the working substance to the exterior or vice versa; a thermally insulated process.

Adiabatic rate of cooling with ascent for dry air.—Very nearly constant in the troposphere at 3° C. per 1,000 feet. (See *adiabat.*)

Adiabatic rate of cooling with ascent for saturated air.—A rate which varies chiefly with the temperature and hence has no fixed value.

Advection.—The process of heat transfer by horizontal air movement.

Aerology.—The portion of meteorology concerning the free atmosphere.

Air mass.—An extensive body of air which approximates horizontal homogeneity.

Altimeter.—An instrument used to measure altitude by means of indicating changes of altitude that result in variations in atmospheric pressure.

Anemograph.—A recording wind velocity and direction instrument.

Anemometer.—An instrument for measuring the velocity of the wind.

Aneroid barometer.—An instrument showing atmospheric pressure by the movements of the elastic top of an exhausted metallic box.

Anticyclone.—A region in which the barometric pressure is higher than the surrounding air. The wind moves clockwise about the center of an anticyclone.

Arctic air.—Air that has its source region over the arctic (or antarctic) ice and snow-covered areas.

Arctic smoke.—A thin whispy fog that occurs chiefly when cold air moves over a much warmer surface.

Ascendant.—A vector giving the direction and amount of the most rapid rate of increase of a given function, as pressure.

Atmospheric circulation.—The general wind system of the earth. Also called the "general circulation."

Barograph.—A self-recording barometer.

Barometer.—An instrument for indicating atmospheric pressure.

Blizzard.—Strong winds with accompanying cold and snow.

Bumpiness.—A flying sensation usually caused by instability of the air.

Buys-ballott's law.—The law which states that if an observer in the northern hemisphere stands with his back to the wind, lower pressure is on his left.

Centigrade.—A temperature scale with 100° between the freezing and boiling points of water, the freezing point being at 0° and the boiling point at 100°. Five centigrade degrees equal 9 Fahrenheit degrees.

Cloudburst.—A sudden downpour of rain usually accompanied by a thunderstorm.

Cold front.—The discontinuity in front of a wedge of cold air which is displacing warmer air in its path.

Condensation level.—The level where the process of formation of water from water vapor begins.

Conditional instability.—A vertical distribution of temperature such that the layer is stable for dry air but unstable for saturated air.

Convection.—The transport of heat by vertical air movements.

Convective condensation level.—The condensation level in free convections (usually higher than the lifting condensation level).

Convective ice crystal level.—Level at which ice crystals form in air being lifted by a free convection current. (This level is somewhat higher than the usual ice crystal level due to the fact that more heat is necessary for free convection.)

Convective instability.—A vertical distribution of temperature and moisture such that lifting of the entire layer will eventually lead to instability with respect to dry air. In convective instability the equivalent-potential temperature decreases with elevation.

Convergence.—A state of air movement in which the air is moving inward within a given region. The opposite of divergence.

Curl.—Used to represent the visible protruding portions of cumuliform clouds.

Curve.—The line joining the significant points of an aerological sounding.

Cyclone.—A system of winds circulating about a center of relatively low barometric pressure in a counterclockwise direction.

Deformation axis.—The line of outflow in a deformation field of motion.

Deformation field of motion.—A field of moving particles that combine convergence and divergence.

Density.—The mass of a substance per unit of its volume.

Depegram.—A curve representing the behavior of the dew point with pressure changes for a given sounding drawn on the tephigram.

Depression.—Synonym for "cyclone".

Dew.—Moisture condensed from the atmosphere in small drops upon plants and other bodies which radiate heat well.

Dew point.—The temperature to which the air must be cooled in order to become saturated.

Discontinuity.—A zone of comparatively rapid transition of the meteorological elements. These discontinuities are not mathematically abrupt but are rapid transitions compared with the ordinary transitions in one and the same air mass. (Practically synonymous with *front.*)

Diurnal heating.—Heating that takes place daily in a certain cycle from day to day.

Divergence.—A state of the atmosphere when air is flowing outward from a given region.

Doldrums.—Those parts of the ocean near the equator where calms prevail.

Drizzle.—Precipitation consisting of numerous and very small droplets.

Dry air.—Air which is not saturated.

Dust.—Pulverized earth carried aloft by the wind.

Eddy.—A whirl or backward circling current of water or air.

Equatorial air.—Air originating in equatorial regions.

Equivalent-potential temperature.—The temperature a given air particle would have if it were brought adiabatically to the top of the atmosphere (that is, to zero pressure) so that along its route all the moisture were condensed (and precipitated), the latent heat of condensation being given to the air, and then the remaining dry sample of air compressed adiabatically to a pressure of 1,000 millibars.

Equivalent-potential temperature diagram.—See *Rossby diagram.*

Equivalent temperature.—The temperature a particle of air would have if it were made to rise adiabatically to the top of the atmosphere (that is, to zero pressure) in such a manner that all the heat of condensation of the water vapor were added to the air and the sample of dry air were then brought back adiabatically to its original pressure.

Fahrenheit.—A temperature scale in which the freezing point of water is 32° and the boiling point is 212°. Nine degrees Fahrenheit equal 5 degrees centigrade.

Foehn wind.—A dry wind blowing down the leeward slopes of mountains that is warmed by adiabatic heating.

Forced convection.—The process by which heat is transposed from one level to another by mechanical movement of the mass containing the heat.

Friction layer.—The lower layer of the atmosphere (usually 1,500 to 3,000 feet thick) in which friction with the earth's surface affects the movement of air. (Synonymous with turbulent layer.)

Front.—The discontinuity between two juxtaposed currents of air possessing different densities. Most frequently, fronts represent the boundary between different air masses.

Frontogenesis.—The creation of fronts generally brought about through the horizontal convergence of air currents possessing widely different properties.

Frontolysis.—The destruction of fronts generally brought about by horizontal divergence at the discontinuity zone.

Frost.—Crystals of ice deposited in the same manner as dew.

Gale.—A wind of force 8 on the Beaufort scale.

Glaze.—A deposit of clear, amorphous ice. (Synonymous with clear ice.)

Gradient.—A vector giving the direction and amount of the most rapid rate of decrease of a function, as temperature or pressure. The pressure gradient is the change of barometric pressure per unit of distance in the direction of the most rapid rate of decrease of pressure. The vertical temperature gradient is called the "lapse rate".

Gradient wind.—The wind that blows along curved isobars with a velocity corresponding to the spacing of the isobars. The wind at 2,000 feet above the surface is often referred to as the gradient wind.

Gust.—A rushing or driving of the wind, sudden and of short duration.

Hail.—Frozen rain, falling in pellets.

High.—A high-pressure area.

Horse latitudes.—Regions of calm or light variable winds within the subtropical belts of high pressure. So called in Colonial times when vessels carrying horses from New England to the West Indies were sometimes obliged, when detained there, to throw overboard part of their cargo for want of water.

Humidity.—The amount of water vapor in the air.

Hurricane.—Wind of force 12 on the Beaufort scale. A tropical cyclone, especially one in the West Indies.

Hygrograph.—A recording hygrometer.

Hygrometer.—An instrument for measuring the humidity or hygrometric state of the atmosphere.

Instability.—A vertical distribution of temperature such that the layer of air is unstable; if unsaturated, the air temperature decreases more rapidly than the dry adiabatic lapse rate, and if saturated, the air temperature decreases more rapidly than the moist adiabatic lapse rate.

Instability showers.—Showers caused by air becoming unstable, such as the rapid warming of the lower layers of a cold current as it moves over a relatively warm surface. In most cases there is an appreciable addition of moisture to the lower layers; for example, when a polar continental current moves over a body of warm water.

Inversion.—Layer in which the temperature increases with increasing altitude instead of the normal decrease.

Isallobar.—A line joining points of equal barometric tendency.

Isallobaric chart.—A chart with isallobars drawn on it.

Isallobaric gradient.—A vector representing the direction and magnitude of the most rapid rate of decrease of pressure tendency.

Isobar.—A line joining points of equal barometric pressure.

Isoline.—A line joining points of equal values (pressure, temperature, etc.).

Isotherm.—A line joining points of equal temperature.

Lapse rate.—The existing rate of change of an element, commonly pressure or temperature, with height in a given layer of the atmosphere.

Level of free convection.—The level at which air rises by its own thermal lift.

Lightning.—A sudden flash of light caused by the discharge of electricity between two electrified regions of clouds or between a cloud and the earth.

Line squall.—Sudden bursts of wind, often accompanied by rain or snow, occurring simultaneously along a line, usually a cold front.

Low.—A low-pressure area, a cyclone, or a depression, usually caused by a wave on a front.

Mechanical instability.—A lapse rate such that the air density increased with elevation; for this condition the lapse rate must be greater than 10° C. per 1,000 feet.

Mechanical lift.—Any lift imparted to an air mass by its or another's kinetic energy—not that due to thermal lift.

Meteorograph.—An apparatus used in upper air soundings that automatically records temperature, humidity, and pressure.

Meteorology.—The science of the atmosphere.

Mixing ratio.—The mass of water vapor per unit mass of perfectly dry (absence of water vapor) air. $w=622e/(p-e)$ grams per kilogram.

Modification of air mass properties.—The change in values of the meteorological elements within an air mass due to such influences as radiation, turbulence, subsidence, convergence, etc. These modifying influences tend to destroy the original horizontal homogeneity of the air mass.

Monsoon.—Winds that consistently blow onshore during the summer and offshore during the winter due to the temperature differential between continental and maritime areas.

Negative area.—The area on a tephigram enclosed between the path of the rising particle and the surrounding air when the rising particle is at every stage in its ascent colder than the environment.

Nephoscope.—An instrument used in the observation of clouds to determine their direction, velocity, motion, and elevation.

Neutral equilibrium.—A vertical distribution of temperature such that a particle of air displaced from its level neither assists nor resists the displacement; that is, at every level the density of the displaced particle is equal to that of the surrounding air. In the case of dry air, the corresponding lapse rate is that of the dry adiabat; in the case of saturated air, the saturation adiabat.

Occluded front or occlusion.—The front formed when and where the cold front overtakes the warm front of a cyclone. Occlusion is the

term used to denote the process whereby the warm air of the cyclone is forced from the surface to higher levels.

Orographic rain.—Rain caused by the lifting of air up the slopes of mountain ranges.

Partial potential temperature.—The temperature a given air particle would have if it were reduced adiabatically from the pressure exerted solely by the dry air to a pressure of 1,000 millibars.

Penetrative convection.—Small convective up currents locally penetrating an overlying more stable layer without generally or greatly altering the existing atmospheric stratification.

Pilot balloon.—A small balloon filled with hydrogen that is released by an observer, who, by the use of a theodolite, is able to determine wind velocity and direction from the movement of the balloon.

Polar air.—Air originating in the polar regions.

Polar front.—The frontal zone between air masses of polar and those of tropical origin.

Positive area.—The area on a tephigram enclosed between the path of the rising particle and the surrounding air when the rising particle is at every stage in its ascent warmer than the environment.

Potential temperature.—The temperature a given particle of air would have if it were reduced adiabatically to a pressure of 1,000 millibars.

Precipitation.—The deposition of moisture from the atmosphere upon the general surface of the earth.

Pseudo-adiabatic.—The process wherein a saturated air particle undergoes adiabatic transformations, the liquid water being assumed to fall out as it is condensed.

Radio meteorograph (radio-sonde).—An instrument that automatically records temperature, humidity, and pressure as it is carried aloft by a hydrogen-filled balloon. It records by a system of breaks in radio code that is transmitted automatically. A parachute carries the instrument to earth after the balloon bursts.

Rain.—Water drops that fall from clouds.

Rectilinear.—Pertaining to, or consisting of, a right line or lines.

Relative humidity.—The ratio of the actual vapor pressure and the maximum vapor pressure possible at the same temperature.

Representative observations.—Those which give the true or typical conditions of the air mass; hence they must be relatively uninfluenced by local conditions and taken from outside the transition zones and fronts.

Rossby diagram.—A thermodynamic diagram making use of the highly conservative air mass properties; partial potential temperature, equivalent-potential temperature, and mixing ratio.

Sandstorm.—A high wind which carries dust or sand with it.

Scud.—Patches of low, rapidly drifting clouds.

Secondary fronts.—Fronts which develop at some distance from the principal fronts of the cyclone. These fronts are often the result of dynamic effects behind the cold front.

Shower.—Isolated precipitation falling from cumuliform clouds.

Sleet.—Frozen rain.

Slope of a front.—The tangent of the angle formed by the discontinuity surface and a horizontal plane.

Snow.—Precipitation in the form of minute ice crystals formed by sublimation of the water vapor in the air and usually falling in irregular masses or flakes.

Source region.—An extensive area of the earth's surface characterized by sufficiently uniform surface conditions and which is so placed in respect to general circulation that masses of air may remain over them sufficiently long to take on fairly definite properties.

Specific humidity.—The mass of water vapor in a unit mass of moist air. $q=622\ e/p$ grams per kilogram.

Squall.—A sudden burst of wind usually accompanied by rain or snow.

Squall head.—The piled-up cold air at the cold front, sometimes taking the form of an overhanging tongue.

Stability.—A vertical distribution of temperature such that particles will resist displacement from their level.

Storm.—A wind of force 11 on the Beaufort scale. There are also various types of storms such as thunderstorm, snowstorm, rainstorm, duststorm, and sandstorm.

Stratification.—A layering of the atmosphere so that each layer is characterized by a particular temperature distribution and moisture content. Instability tends to wipe out stratification as it brings about mixing.

Stratosphere.—A layer of the atmosphere above the troposphere in which the air is stable with an isothermal lapse rate or a slight inversion.

Subsidence.—An extensive sinking process most frequently observed in polar anticyclones. The subsiding air is dynamically warmed and made more stable.

Surface of discontinuity.—The sloping boundary zone between air masses of different properties. (See *Discontinuity.*)

Synoptic chart.—A weather map showing the weather conditions over a large area at a given time.

Tephigram.—A thermodynamic diagram for estimating the quantity of available convective energy in the overlying air column; also

applied to the graph of an individual sounding plotted with coordinate temperature and entropy.

Thermal.—Pertaining to, determined by, or measured by heat.

Thermograph.—A recording thermometer.

Thermometer.—An instrument for measuring temperature.

Thunder.—The sound that accompanies lightning, due to the disturbance of the air by the electrical discharge.

Tornado.—A very violent storm of small extent, usually occurring along or ahead of a cold front, accompanied by rain or hail and usually thunderstorms, and having cyclonic rotation with a funnel-shaped cloud.

Trade wind.—A steady wind that blows from the subtropical high pressure belts to the region of lower pressure near the equator, from the northeast in the northern hemisphere, and from the southeast in the southern hemisphere.

Transition zone.—The zone at a discontinuity wherein the properties are neither characteristic of one air mass nor the other, but lie somewhere between the two. It is now customary to assume that all the air in the transitional zone belongs to the colder air mass, the air in warm sectors being considered more nearly homogeneous.

Translation.—A motion in which all points of the moving body have at any instant the same velocity and direction of motion.

Tropical air.—Air originating in the low latitudes, chiefly in the regions of the subtropical anticyclone.

Tropical cyclone.—A cyclone of great intensity, usually round, originating in the tropics, and usually having a diameter of about 500 miles. (See *Hurricane.*)

Tropopause.—The upper limit of the troposphere.

Troposphere.—The lower layer of the atmosphere in which there is normally a temperature decrease with height of 2° C. per 1,000 feet. It is the convective portion of the atmosphere.

Trough.—An elongated area of relatively low pressure usually extending from a cyclonic center and continuing a front along the line of minimum pressure.

Unstable.—A vertical distribution of temperature such that particles of air, because of their lesser or greater density than the surrounding air, will rise or sink of their own accord once given an initial impetus up or down.

V-shaped depression.—A trough containing a well-defined front, usually a cold front, with V-shaped isobars.

Vapor pressure.—The partial pressure of the air exerted solely by the water vapor molecules.

Virga.—Trailer of rain or snow from clouds.

Visibility.—The maximum distance at which ordinary objects may be identified.

Vortex.—A portion of fluid whose particles have rotary motion.

Warm front.—The discontinuity at the front of a warmer air mass which is displacing a retreating colder air mass.

Warm sector.—The air enclosed between the cold and warm fronts of a cyclone.

Waterspout.—A tornado cloud at sea.

Wave disturbance.—A deformation produced along a front. These waves travel along the discontinuity surface producing new disturbances.

Wedge.—An elongated area of relatively high pressure extending from an anticyclone.

Wind.—Air in motion.

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